

Science and Mathematics Education Centre

**Development and Application of a Diagnostic Instrument to
Evaluate Secondary School Students' Conceptions of Electrolysis**

Ding Teng Sia

**This thesis is presented for the Degree of
Doctor of Science Education
of
Curtin University of Technology**

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DECLARATION

This thesis contains no material which has been accepted for the award of any other degree in any university. To the best of my knowledge and belief, this thesis contains no material previously published by any other person except where due acknowledgement has been made.

Signature: 

Date: 23 June 2010

ABSTRACT

A two-tier multiple choice diagnostic instrument consisting of 17 items was developed to evaluate students' understanding of basic electrolysis concepts. This study which used mixed qualitative and quantitative methods, was conducted in 2006 and 2007 to produce the final instrument. Subsequently, the final instrument was administered to 16 year-old secondary school students ($N = 330$) who had completed the first year of a two year chemistry course. The instrument was found to have a high Cronbach's alpha reliability coefficient of 0.85 which is greater than the threshold value of 0.5 quoted by Nunally and Bernstein (1994). Analysis of students' responses demonstrated good discrimination indices between the top and bottom groups of low- and high-achieving students, with the indices ranging from 0.42 to 0.84 for 16 items and 0.28 for one item. The analysis also identified 29 alternative conceptions that involved a variety of electrolysis concepts relating to the nature and reaction of the electrodes, the migration of ions, the preferential discharge of ions, the products of electrolysis, and changes in the concentration and colour of the electrolyte. In addition, there was a mismatch between students' confidence in answering the items and their correct responses. Students' level of confidence in providing correct responses to these items ranged from 44% to 72%, but the actual correct responses ranged from 19% to 53%. As no other similar instrument has been reported in the research literature, this instrument is a convenient diagnostic tool that teachers could use to identify students' preconceptions prior to introducing the topic. In addition, using the instrument in formative assessment during classroom instruction will enable teachers to identify students' alternative conceptions and institute appropriate remediation measures with the students concerned.

DEDICATION

This thesis is dedicated to
Almighty God, for giving me the wisdom and health.

My loving husband, Philip and sons, Jonah and Joel for their invaluable support and
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CHAPTER ONE

INTRODUCTION

THE PROBLEM

This study addresses the problem of how to diagnose secondary students' (15 to 16 years old) understanding and alternative conceptions of electrolysis using a pencil and paper test.

CONTEXT OF THE STUDY

Science education in Malaysia has undergone different stages of reforms due to both internal and external influences. One of the latest changes is the introduction of the Integrated Curriculum for Secondary Schools in 1988 conducted in the Malay language. With the advancement of science and technology together with globalisation, the curriculum is going through another change, that is, the implementation of the policy of PPSMI (Pengajaran dan pembelajaran Sains dan Matematik dalam bahasa Inggeris) which means the teaching and learning of Science and Mathematics in English, starting with Form One in 2003, and Form Six in 2003. The first batch of students taking Chemistry in Form Four using English medium started in the year 2006. This study involved Form Four students who commenced learning Chemistry in English in 2007.

What is the reason behind the Malaysian government's decision to teach Science and Mathematics in English? According to Mohamad (2004, p.3), "The fact that globalisation has come does not mean we should just sit by and watch as the predators destroy us." Within the Asia Pacific region, one can see the rise of India as an information technology hub with workers competent in English, and the Philippines has a highly educated workforce competent in English. Competitors are forging ahead with new knowledge-economy fields, China and Taiwan in biotechnology, India in pharmaceuticals and software engineering, and Singapore in biotechnology and medicine. In natural science, mathematics, computer science,

engineering, science and technical fields, Malaysia compares unfavourably with Japan, Korea, New Zealand, Philippines, Taiwan and Thailand with regard to knowledge-skilled workers; Malaysia lags behind its major competitors. The performance of science as reported in one study by Trends in International Mathematics and Science Survey 1999 (TIMSS, 1999) is shown in Table 1.1. Malaysia ranked 22 out of 38 nations with an average score of 488.

Table 1.1 Performance of science by different nations in 1999

Nation	Average Score
Chinese Taipei	569
Singapore	568
Hungary	552
Japan	550
Korea, Republic of	549
Netherlands	545
Australia	540
Czech Republic	539
England	538
Finland	535
Slovak Republic	535
Belgium-Flemish	535
Slovenia	533
Canada	533
Hong Kong SAR	530
Russian Federation	529
Bulgaria	518
United states	515
New Zealand	510
Lavia-LSS	503
Italy	493
Malaysia	492
Lithuania	488
Thailand	482
Romania	472
Average of 38 nations =	488

On 20 July 2002 the Minister of Education announced the decision to teach science and mathematics in English (PPSMI). The Ministry of Education in Malaysia proposed the phased implementation beginning in 2003 and being completed in 2008 as shown in Table 1.2.

Table 1.2 Phased implementation of teaching science and mathematics in English in the secondary school level

Year	2003	2004	2005	2006	2007	2008
Secondary School Level	Form 1	Form 1, 2	Form 1, 2, 3	Form 1, 2, 3, 4	Form 1, 2, 3, 4, 5	Form 1, 2, 3, 4, 5, 6

All public examinations from the years 2003 to 2007 were in two languages, English and Malay. Students can answer part or all the examination questions in English or Malay. Starting from 2008, questions and answers in public examinations are completely in English.

In implementing the decision, the Ministry of Education supplied schools before January 2003 with the following equipment: 42,440 laptops, 43,457 LCD projectors and screens, 23,743 trolleys, 25,396 speakers and subwoofers, and 1,519 34-inch television sets to make sure the change could be implemented on time with effect from 1 January 2003 (Curriculum Development Centre of Malaysia, 2003). That science and mathematics are taught in English is an issue of national survival, a national economic and strategic agenda as well as an education agenda. Malaysian citizens have to work together to embrace English and the science and technological knowledge that come with it to progress as a developed nation.

Compared to TIMSS 2003, the standard of science in Malaysia in TIMSS 2007 compared to other nations has not improved greatly. In 2003, Malaysia with an average scale score of 510 ranked 20 out of 45 nations with the international average of 474 (TIMSS, 2003); in 2007, Malaysia with an average score of 471 ranked 21 out of 56 nations with the international average of 500 (TIMSS, 2007). Though Malaysia has not shown much progress as compared with the ranking of 22 out of 38 nations in 1999, she is maintaining her ranking with other nations included. The comparison is summarized in Table 1.3.

Table 1.3 Comparisons of ranking of Malaysia in different years of TIMSS

TIMSS in Year	Average Score in Science	International Average	Ranking
1999	492	488	22/38
2003	510	474	20/45
2007	471	500	21/56

It should be noted that “in 2003 using the international average may have given the erroneous impression that some countries at the eighth grade science had improved, when actually it was only the international average had become lower. Thus to avoid misinterpretations based on movement of international average between cycles, TIMSS 2007 adopted the fixed average approach” (TIMSS, 2007, p. 33), with the average scale score set at 500 and for all future cycles.

Lately in 2009, many educationists are still in favour of the PPSMI policy to be continued, recognizing the benefits this policy has brought. Education Director-General Datuk Alimuddin Mohd Dom clarified the government’s position that “Education policy cannot be changed so quickly. Education is like a ship, takes time to move, not like a speedboat” (“Assessment On,” 2009, p.6). Alimuddin further announced that “a true assessment of the effectiveness of the teaching of mathematics and science in English policy could only be made in about four years” (“Assessment On,” 2009). He was speaking to reporters after the Ministry of Information’s Current Issues Briefing program regarding the issues and challenges on the policy at Auditorium Perdana, Angkasapuri.

Sarawak Teachers’ Union president William Ghani in supporting the Director-General had this to add, “If the use of English to teach mathematics and science is abolished, students are likely to shun these subjects in future, thus putting brakes on the nation’s effort to produce quality human capital (“Students May,” 2009, p.7). Under the current economic climate, Ghani considered that it is best to carry on the government’s decision regarding the PPSMI policy. Another local prominent social activist, Mr. Lee Lam Thye remarked that “English has been the depository language of knowledge and our children must be fluent in it for us to stay competitive on the

global stage” (“Give It,” 2009, p.1). Mr. Lee explained that past Primary-6 assessment results had shown encouraging signs about the policy, and he urged the people to understand and appreciate the real objectives of the policy, which was mooted with the best interest of future generations in mind. Dr. Ting Chek Ming, a former senior lecturer at a local university college in Sarawak, also showed support for this policy to be continued. He favours the medium of instruction in English language for science and mathematics in secondary education to be continued as this will subsequently help students doing research at tertiary level due to easy access to reference and research materials in English. Ting added “people should move with the current trend if they do not want to be left behind in the borderless world” (Boon, 2009).

When this study was conducted in 2007, the policy of teaching and learning of science and mathematics in English (PPSMI) has been implemented for 5 years. The latest twist is that this policy now seems to be controversial, since the Education Minister of Malaysia, Tan Sri Muhyiddin Yasin has announced that the teaching and learning of science and mathematics will be reverted to the Malay language for Year Four, Form One and Form Four classes starting in year 2012 (Adib, 2009; Loh, 2009). This new policy of using Malay language to teach science and mathematics will go ahead despite reasons put forward by the former Prime Minister of Malaysia, Tun Dr Mahathir Mohamad (Dr M, 2009) that “the teaching of science and mathematics in English should be continued to ensure Malaysian students, especially the Malays, are not left behind.” He stressed that the change to teach the two subjects in English from Malay language was to ensure that students could master them and at the same time become more proficient in English, which is the number one language in the world. “It is not aimed at neglecting Bahasa Malaysia (Malay language). Furthermore, most publications on science and mathematics are in English.”

Clearly, this latest decision is not pleasing everyone while Tan Sri Muhyiddin Yassin denied that the PPSMI policy had failed, and he explained that when the policy of PPSMI was introduced in 2003 it was heavily criticized by Chinese educationists and Malay language activists. However, Tan Sri Yassin also noted that a “recent

survey by the independent Merdeka Center showed that 58 per cent of 1,060 voters interviewed supported the PPSMI policy.”

The importance and extent of electrochemistry in our life is also emphasised by Schmidt, Marohn and Harrison (2007) that “electrochemistry plays an important role in curricular, textbooks, and in everyday life” (p. 258). De Jong and Treagust (2002) stated that electrochemistry is ranked by teachers and students as one of the most difficult curriculum domains taught and learnt in secondary school chemistry. They also found that “the number of empirical studies of students’ conceptions and learning difficulties concerning electrochemistry is rather limited when compared with studies concerning many other chemistry topics” (De Jong & Treagust, 2002, p. 318). Similarly, Masrukin (2002) in her study found that 72% of the chemistry teachers interviewed agreed that electrochemistry is a topic which was difficult for students to understand. De Jong and Treagust (2002) reasoned that changes of meaning due to changes of context may cause many students to develop learning difficulties in the understanding of electrochemical concepts, especially in the case of the mixing of contexts, such as the phenomenological one with the particulate one. Johnstone (1999) also believed that students have difficulty with chemistry because of “the tangible macro-science at molecular level” (p. 46). Treagust, Duit and Nieswandt (1999) contended that major learning difficulties arise because the concepts in chemistry, in many ways, contradict intuitive and everyday views of learners. The special language of chemistry also posed problems to the learners (Boo, 1998; Fensham, 1994; Gabel, 1999).

As a secondary school chemistry teacher, I have observed that students have frequently shown misconceptions in the concepts of chemistry, making them feel that studying chemistry is difficult. Therefore, it is of interest to find out what learning difficulties the students face, and their alternative conceptions of electrolysis in particular.

PURPOSE OF THE STUDY

The purpose of the study is to develop a two-tier multiple choice diagnostic instrument pertaining to electrolysis and using the instrument to identify secondary chemistry students' alternative conceptions in electrolysis.

The objectives of the study are to:

1. Identify the concepts and propositional knowledge necessary for secondary chemistry students to understand the topic of electrolysis.
2. Analyse three approved chemistry textbooks used by secondary chemistry students, to compare the concepts and propositional knowledge present in the textbooks with the concepts and propositional knowledge identified in the study.
3. Identify secondary chemistry students' alternative conceptions in electrolysis.
4. Develop a two-tier multiple choice diagnostic instrument consistent with the identified concepts, propositional knowledge and known student alternative conceptions related to electrolysis.
5. Measure secondary chemistry students' understanding of the concepts and propositional knowledge related to electrolysis through the use of the two-tier multiple choice diagnostic instrument developed.
6. Explain the relationship between the students' correct answers and their level of confidence.

RATIONALE FOR THE STUDY

Based on the literature review, no study on students' understanding of the concepts and propositions pertaining to electrolysis in Malaysia has been reported, so this study deals with defining the content framework of the Malaysian Certificate Examination chemistry syllabus, and developing a two tier multiple choice diagnostic instrument to assess students' understanding of electrolysis concepts.

Schmidt et al. (2007) investigated secondary school students' problems in learning electrochemistry at an introductory chemistry level and the study covered four main areas of electrolytes; transport of electric charges in electrolyte solutions; the anode

and the cathode; and the minus and plus poles. They also used the systematic development of 29 multiple-choice items on electrochemistry, but this study looked into the development of a diagnostic test for electrolysis for Form Five secondary students. Schmidt et al. (2007) suggested that their study “also provides readers with validated and reliable test items that can be used to explore student understanding of electrochemistry in their own context” (p. 278). At the time this study was carried out with the test items, the author had no knowledge of Schmidt et al.’s study which is reviewed in Chapter 2.

Electrochemistry is a difficult subject and not much research has been conducted in this area as highlighted by De Jong and Treagust (2002); therefore, there is a need for more research, in particular about electrolysis. Electrochemistry is considered to be a rather difficult topic by many students as well as teachers (De Jong & Treagust, 2002; Masrukin, 2002) and research has shown that students have a lot of misconceptions concerning electrochemistry (Sanger & Greenbowe, 1997a; 1997b; Garnett & Treagust, 1992b). In another perspective, Brandt, Elen, Hellemans and Heerman (2001) reported that electrochemistry is a topic for which teachers seldom use adequate visualization methods. Real life experiments are seldom done in ordinary teaching because of the micro scale of these phenomena.

This study also focused on a list of conceptual and propositional knowledge statements as Garnett, Garnett and Hackling (1995) suggested that such a list to clarify the knowledge base will provide a sound starting point.

Textbooks are the main sources of information for teachers and students. Masrukin (2002) reported “students find the textbooks and the variety of reference books available confusing” (p. 18) while Sanger and Greenbowe (1999) reviewed 10 introductory chemistry textbooks about electrochemistry and found many statements that would justify students’ developing alternative concepts. Hence the need to analyse textbooks used to see whether there is a possible source of alternative concepts, or any inconsistencies. Teachers need to be familiar with, and be able to identify the students’ possible alternative conceptions if they are to assist students in learning a topic meaningfully (Peterson, 1986).

The level of confidence students have in answering the items in the electrolysis diagnostic instrument is another area of interest in this study. It aims to find a relationship between the confidence level and getting the correct answer.

SIGNIFICANCE OF THE STUDY

The findings of this study will contribute to the classroom teachers of chemistry, curriculum writers and research workers in science education. The diagnostic instrument to be developed will assist teachers to assess their students' understanding of the concepts and propositional statements, and identify any alternative conceptions. Investigating students' conceptions not only reveals important insights into students' ways of thinking and understanding, but can also help teachers to see their own views in totally new ways that can result in a major reconstruction of their science knowledge or their conviction of how this knowledge should be presented in class (Duit, Treagust, & Mansfield, 1996).

RESEARCH QUESTIONS

Six research questions which are being considered in this study of the understanding and conceptions of electrolysis of secondary students are related to the six objectives.

1. What are the concepts and propositional knowledge statements necessary for secondary chemistry students to understand the topic of electrolysis?
2. Are the concepts and propositional knowledge present in the three approved chemistry textbooks used by secondary chemistry students consistent with the concepts and propositional knowledge identified in the study?
3. What do secondary chemistry students understand about the concepts and propositional knowledge related to electrolysis?
4. What are the difficulties in developing a diagnostic test consistent with the identified concepts, propositional knowledge and known student alternative conceptions related to electrolysis?

5. What is the extent of secondary chemistry students' understanding and alternative conceptions of the concepts and propositional knowledge related to electrolysis as identified through the use of a diagnostic test?
6. What is the relationship between the students' correct answers and their level of confidence?

METHODOLOGY

In this study, four procedures were used to limit and specify the subject content related to electrolysis. They were the extraction of parts of the Malaysian School Certificate chemistry syllabus relevant to electrolysis, the development of a concept map, the identification of propositional knowledge statements, and the relating of the propositional knowledge statements to the concept map. The extract of the syllabus, concept map and list of propositional statements were reviewed by two tertiary chemistry lecturers and three experienced secondary school chemistry teachers for accuracy and relevance.

The literature was reviewed to determine students' knowledge and alternative conceptions in topics related to electrolysis. In 2006, semi-structured interviews of Form Four students (15 to 16 years old) were conducted to explore their understanding of electrolysis. A free response test on electrolysis, designed using the data collected from the interviews and past years examination questions, was administered to one class of Form Five students in April, 2007, and the data collected was used to develop the first version of the two-tier multiple choice diagnostic instrument. Further studies resulted in the second and final version of the diagnostic instrument, the 'Electrolysis Diagnostic Instrument' (EDI). The EDI was administered to 330 Form Four students from three secondary schools in Kuching, Malaysia. The results obtained were analysed and the alternative conceptions on electrolysis that the students had were identified.

OUTLINE OF THE STUDY

A brief description outlining the content of the remaining chapters of the research is given below. The literature review in Chapter 2 establishes the theoretical and methodological framework for the study. Chapter 3 provides the propositional knowledge statements and concept map pertaining to electrolysis as required for students who are preparing for Malaysian School Certificate chemistry examinations. The content of three secondary chemistry textbooks on electrolysis is analysed in Chapter 4. The first study using interviews with students is described in Chapter 5. The development of the two-tier multiple choice diagnostic instrument is described in Chapter 6. The results following the administration of the final version of the diagnostic instrument to secondary chemistry students are given in Chapter 7, together with the interpretation of the results. Finally, the conclusions, recommendations, and discussion of the limitations of the study are presented in Chapter 8.

The flow diagram in Figure 1.1 presents a summary of the different stages undertaken in Studies 1, 2, 3 and 4 in the development of the electrolysis diagnostic instrument (EDI). The final EDI consisted of 17 two-tier multiple-choice items and a copy of the diagnostic instrument is found in Appendix H.

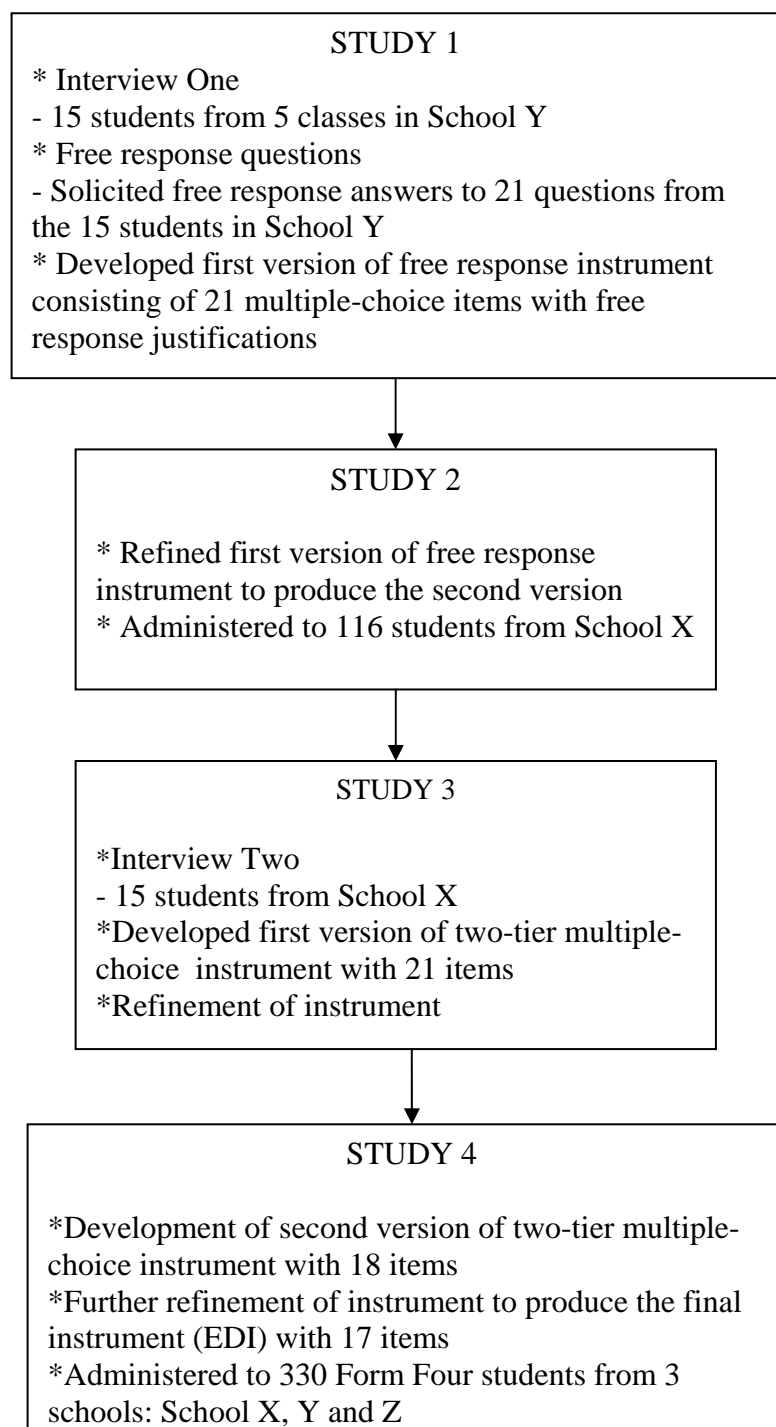


Figure 1.1 Flow diagram summarizing Studies 1, 2, 3, and 4

SUMMARY

The main purpose of this study was to develop a written diagnostic instrument which could be used to determine secondary students' understanding as well as identify alternative conceptions in electrolysis following instruction in the topic. This study

was designed to enable teachers and curriculum writers to be aware of students' alternative conceptions so that they can develop appropriate teaching strategies and materials to help students better understand electrolysis.

CHAPTER TWO

LITERATURE REVIEW

INTRODUCTION

This chapter provides a theoretical and methodological framework for this study on the development of a two-tier multiple choice diagnostic instrument to measure secondary students' understanding and alternative conceptions of electrolysis. There are seven main sections. The first section describes learning theories relevant to the study. The second and third sections review the nature of alternative conceptions and studies of alternative conceptions in science, with particular reference to chemistry. Some methodologies for determining alternative conceptions are outlined in the fourth section. The fifth section deals with the studies done on electrochemistry. A review regarding confidence and attitudes related to performance is described in the sixth section. Finally, the role and analysis of textbooks are described in the seventh section.

LEARNING THEORIES

This section describes theories of learning which are relevant to this study. Cognitive theories of learning such as Piaget (1977) and Ausubel (1968) help provide an understanding of how students learn and understand concepts in science. Child development theories of Piaget viewed learning as arising from children's acting on the world (Tytler, 2002a). The learners develop different stages of cognitive development at different ages, and can handle most successfully, the learning tasks which correspond to their stage of development (Adey, 1992).

Ausubel's (1968) emphasis was on meaningful learning because humans are able to acquire and store a "vast quantity of ideas and information represented by any field of knowledge" (p. 58). However, the learner must want to learn meaningfully and must have prior knowledge necessary to make the learning task meaningful. This learning theory is important because it links students' preinstructional conceptions to

subject-matter knowledge in order to achieve meaningful learning (Ausubel, 1968; Jung, 1993; Tytler, 2002a). Indeed research has shown that the degree of meaningfulness of a learning task can vary dependent on the adequacy of the learner's relevant prior knowledge (Novak, 1976). Ausubel (1968) contrasted meaningful learning with rote learning, which he described as "purely arbitrary associations" (p.24). In acquiring knowledge, the learner needs to be an active participant and not a passive recipient in the process. In brief, the learner is responsible for his/her learning (Novak, 1988).

Consistent with the theories of Piaget and Ausubel, learning is viewed as the construction of personal meaning (Tytler, 2002a) where the learner's existing knowledge has significant effects on new learning (Driver, 1995; Duit, 1995; Jonstone, 1999). Furthermore, students' understandings are highly contextual (Rahayu & Tytler, 1999; Tytler, 2000) and this notion can be useful in guiding instruction. Contextualising science instruction involves utilising students' prior knowledge and everyday experiences as a catalyst for understanding challenging science concepts and can be used as a means to facilitate student learning (Rivet & Krajcik, 2008). It should be noted that students do not abandon their intuitive conceptions once they learn a science concept, but carry them alongside, to be used in situations where the science concepts are not yet used (Rahayu & Tytler, 1999; Tytler, 2000).

Concepts are acquired early in life, that is, children spontaneously develop theories and explanations for things and phenomena that they encounter in their everyday life (Driver, Squires, Rushworth, & Wood-Robinson, 1994; Novak, 1988). These conceptions are generally resistant to change because they are coherent, sensible and fit with the students' domain of experience. For instance, Hand and Treagust (1991) interviewed 78 pupils, aged 15, about their conceptions of acids. They found that the two major conceptions were 'acids eat material away' and 'acids can burn you'. These observations are likely to be based on what they have seen in their laboratories, for example, a few drops of concentrated sulphuric acid on the bench will damage that spot of the bench. This supports Novak (1988) that thinking, feeling and acting are integrated factors that influence students' learning: "students with a constructivist commitment also show more capacity for modifying wrong or

inadequate conceptions” (p. 93), and have negative feelings associated with rote learning and positive feelings when learning is meaningful.

Prior knowledge is important to learning. Many studies in science education support the view that students construct their own understanding based on prior knowledge and beliefs (Driver, et al., 1994; Gunstone, 1995). Ideas are constructed or made meaningful when children integrate them into their existing structures of knowledge. Indeed students construct meanings from what they see or hear that may be different to those intended and are influenced by prior knowledge (Tytler, 2002a).

Besides the cognitive aspects, Huddle, White and Rogers (2000) believed that science concepts, being very complex, can affect students’ learning of the concepts. Macbeth (2000) believed that if students have their own conceptions, they tend to be indifferent to accepted scientific concepts. Therefore, they need to be motivated to focus on the scientific concepts first before teachers can motivate them to give some thought to the concepts. Hogan (2000) highlighted the importance of the learners’ motivational beliefs about themselves and the social aspects of their learning environment in facilitating or hindering conceptual change. Many teachers and students tend to view learning as transferring to memory all the accumulated facts because they are “naïve realists in that they view science and mathematics knowledge as a faithful copy of the ‘world outside’ and not as tentative human construction (Treagust, Duit & Fraser, 1996, p. 2). These students may not accept the responsibility of constructing meaning from the lesson, and the teachers with reproductive conceptions of teaching (Koballa, Graber, Coleman, & Kemp, 2000) will continue to fill their students’ blank minds with knowledge.

ALTERNATIVE CONCEPTIONS

This section defines the term ‘alternative conception’ used in this study and discusses how alternative conceptions arise, and how they influence teaching and learning in science.

Johnstone (2000) stated that when a person tries to store material in long term memory and cannot find existing knowledge to link it, he/she may try to adapt the

knowledge to fit somewhere, thus giving rise to erroneous ideas. When students' existing conceptions differ from those commonly accepted in the disciplines, they are termed as alternative frameworks (Driver & Easley, 1978), misconceptions (Cho, Kahle, & Nordland, 1985; Driver & Easley, 1978), student conceptions (Duit & Treagust, 1995; Tytler, 2002a), alternative conceptions (Abimbola, 1988; Hewson 1981; Tytler, 2002b), intuitive conceptions (Duit, 1995) or children's science (Osborne, Bell & Gilbert, 1983). The term 'misconception' which is now out of favour (Tytler, 2002a, p.15) "implies that ideas students have are simply wrong, when judged against 'correct' scientific conceptions." Duit and Treagust (1995) stated that alternative frameworks suggest that the students' conceptions are effective in daily life and hence valuable to them, while Osborne, et al. (1983) believed that students' conceptions should be taken seriously because they formulate ideas in a way that is similar to those of scientists. Vosniadou (1994) considered misconceptions to be spontaneous constructions which are often generated on the spot, and not deeply held specific theories.

Students' alternative conceptions "in many cases form useful prior knowledge that a teacher can build on", however, these conceptions "have proved surprisingly difficult to shift, and can offer a serious barrier to effective teaching" (Tytler, 2002a, p. 15). Students have various conceptions about science concepts that vary from scientific conceptions (Novak, 1983, 1993; Duit, 2009; Tytler, 2002a; Wandersee, Mintzes & Novak, 1994). Liu (2001) found that inconsistent findings of a scientific concept are inevitable because student conceptions themselves naturally vary from context to context and from student to student.

Duit and Treagust (1995) defined conceptions as "the individual's idiosyncratic mental representations" while concepts are "something firmly defined or widely accepted" (p. 47). Children develop ideas and beliefs about the natural world through their everyday life experiences which include sensual experiences, language experiences, cultural background, peer groups, and mass media (Duit & Treagust, 1995).

Based on research on student learning in science, Tytler (2002a) reported that many of students' conceptions differ in important ways from the view of the world that

scientists have constructed. In fact many of these ‘alternative conceptions’ are similar to views that scientists held in previous eras. When students are presented in formal lessons with science ideas that differ from previous held conceptions, students can accept the science idea and reject the prior idea, or the students can accept the science idea but retain the prior idea (Chinn & Brewer, 1993; Tytler, 2002a).

Possible sources of alternative conceptions are formal lessons and textbooks. Gabel (1989) reported that alternative conceptions of students may result when they are presented with concepts in too few contexts or when concepts are presented beyond their developmental level. McDermott (1988) suggested that some alternative conceptions may arise from failing to integrate knowledge from different book chapters. Harrison and Treagust (1996) found that students were confused between terms with the same word but different context such as the nucleus of a cell and the nucleus of an atom.

However, teachers are often unaware of their students’ alternative conceptions (Treagust, et al., 1996), and for this reason Posner, Strike, Hewson and Gertzog (1982) suggested that teachers “should spend a substantial portion of their time diagnosing errors in thinking and identifying moves used by students to resist accommodation” (p. 226). Wittrock (1994) proposed that identifying and understanding student conceptions will advance science teaching. Similarly, Howe (1996) argued that instead of challenging alternative conceptions directly as inadequate or wrong, one should accept the student’s ideas as a starting point with a view to helping them expand their knowledge. This view was adopted by Grayson (1996) using concept substitution.

Teachers can also be sources of alternative conceptions, and pass them on to their students, such as using imprecise terminology in the way they teach and thereby cause confusion (Chang, 1999; De Jong, Acampo, & Verdonk, 1995; Lee, 1999a; Lee, Goh, & Chia, 1998; Wandersee et al., 1994). In addition, teachers should be aware that textbooks can also contain errors or conflicting illustrations and statements which can give rise to alternative conceptions (Boo, 1998; Ogude and

Bradley, 1994; de Posada, 1999; Garnett, Garnett, & Treagust, 1990; Sanger & Greenbowe, 1999; Wandersee et al., 1994).

STUDIES OF STUDENT CONCEPTIONS IN CHEMISTRY

Electrolysis involves several aspects of chemistry, hence an overview of relevant studies of student conceptions in chemistry is necessary. The difficulties that students have in learning chemistry and students' conceptions of the particulate nature of matter, chemical bonding, and selected chemical reactions are discussed in this section.

Many concepts in chemistry are 'notional, semantic, handed down by authority rather than experienced' (Johnstone, 1999, p. 46) and would be inexplicable without the use of analogies or models (Gabel, 1999). Ross and Munby (1991) pointed out that chemistry concepts are so interrelated that students having difficulty in one topic can be expected to have difficulty with others. To engage in chemical reasoning, students may need to constantly shift between four representational systems (Nakhleh & Krajcik, 1994), the macroscopic, microscopic, symbolic and algebraic, and this causes further difficulties. Johnstone (2000) pointed out that the need to shift between representational systems is "at once the strength of our subject as an intellectual pursuit, and the weakness of our subject when we try to teach it, or more importantly, when beginners (students) try to learn it" (p. 11). He believed that the student may not be able to process and store information in the different representational systems and may "attempt to 'bend' or 'manipulate' the information into a more tangible form" (p. 11), giving rise to alternative conceptions.

Abraham, Grzybowski, Renner and Marek (1992) indicated that formal operational reasoning is required to understand chemistry concepts, to make sense of "the invisible and the untouchable" (Kozma & Russel, 1997, p. 949), but this reasoning may be beyond the ability of many secondary students. Gabel and Bunce (1994) noted that according to the literature, only 30% to 70% of chemistry students operated at a Piagetian formal level in chemistry, and this implied that many students rely on memorisation strategies to deal with difficult concepts.

Abraham, Williamson and Westbrook (1994) found that both reasoning ability and experience with concepts influence the understanding of chemistry concepts. They suggested a spiral curriculum should be adopted for chemical education, with emphasis on concrete experiences for beginning students. Teachers and textbooks need to simplify abstract concepts and use analogies to make the concepts more 'real' to students. Johnstone (1999) however believed that in doing so, the foundations for alternative conceptions are laid because students may make wrong associations and these are difficult to unlearn as well as interfere in new learning (Taber, 1999b). Treagust, et al. (1999) contended that major learning difficulties arise because the concepts in chemistry, in many ways, contradict intuitive and everyday views of learners. The special language of chemistry also poses problems to the learners (Boo, 1998; Fensham, 1994; Gabel, 1999). Andersson (1986) stressed that careful choice of language is very important in the teaching of chemistry as students, lacking the appropriate framework, may misinterpret the words of teachers and textbook authors giving rise to alternative conceptions.

There are many studies into student alternative conceptions in chemistry and summaries of such studies can be found in Driver et al. (1994), Gabel and Bunce (1994), Garnett et al. (1995), Nakhleh (1992), and Duit (2007). Areas of studies pertinent to electrolysis include the particulate nature of matter, bonding, chemical reactions and changes, redox, and electrochemistry.

Particulate nature of matter

The concept of the particulate nature of matter lays the foundation for the understanding of many chemistry concepts (Herron & Nurrenbern, 1999; Nakhleh & Samarapungavan, 1999; Williamson & Abraham, 1995). "The central concept in understanding chemistry is essentially the particulate theory as well as the understanding and the use of the atomic and molecular concepts" (Masrukin, 2002, p. 15). Gomez, Benarroch and Marin (2006) revealed a high degree of coherence in the replies given to different tasks given by 43 students aged 9-22 years concerning the particulate nature of matter. Liu and Lesniak (2006) reported that the progression of students' conceptions on matter from elementary to high school is multifaceted

with different conceptual patterns existing for different substances (water, baking soda, and vinegar).

In probing middle school students' understanding of the composition and particulate (atomic/molecular) structure of a variety of substances, Nakhleh, Samarapungavan, and Saglam (2005) stated that "the fragmentation of middle school students' ideas about matter probably reflects the difficulty of assimilating the microscopic level scientific knowledge acquired through formal instruction into students' initial macroscopic knowledge frameworks" (p. 581).

However, Abraham et al. (1994) found that students at all levels tended not to use atomic and molecular explanations for chemical phenomena. Tsaparlis (1997) argued that "(i) the inability of most or many students to employ formal operations; (ii) the lack of proper knowledge corpus which is a prerequisite for meaningful learning; (iii) the absence of the relevant conceptions from long-term memory" (p. 924) made particulate nature of matter difficult for students to learn. This position is in agreement with Abraham et al. (1992) who stated that students avoided using such explanations because they did not understand them well enough, and this might be linked to students' inability to build mental models that illustrate particulate behaviour (Williamson & Abraham, 1995). Students have problems understanding the particulate nature of matter because "students have to take their existence on faith and build up knowledge structures of molecules and molecular behaviour without having direct experience with molecules" (Fellows, 1994, p. 988).

Basic terms such as particle, elements, compounds, mixtures, as well as atoms, ions and molecules are not well understood and differentiated (Ayas & Demirbas, 1997; de Posada, 1997; del Pozo, 2001; Maskill, Cachapuz & Koulaidis, 1997; Taber, 1996). Ahtee and Varjola (1998) contended that students need to experience different chemical phenomena in order to "realise the variety for which a general explanation in the form of atom theory applies" (p. 315).

Nakhleh and Samarapungavan (1999) suggested that the understanding of the nature of matter requires "acts of imagination" (p. 801) and young students may be able to grasp basic concepts if appropriately taught. Reynolds and Brosnan (2000) also

argued that in the teaching of science “an important part of what we require of students is an act of the imagination” (p. 61). Nakhleh and Samarapungavan (1999) stated that the difficulties that children face have less to do with developmental constraints on their cognitive abilities than with the ontological shifts that are required to switch from a macroscopic to a microscopic view of matter.

Many students from junior high to university level believe that matter exists as a continuous medium rather than as an aggregation of particles, and that atoms and molecules have macroscopic properties such as expanding when heated and having the colour of the substance (Garnett et al., 1995; Lee, Eichinger, Anderson, Berkheimer & Blakeslee, 1993; Nakhleh, 1992; Reynolds & Brosnan, 2000). Harrison and Treagust (1996) reported that some students believed the particles which made up non living things were atoms but particles which made up living things were cells; these students did not realise that cells were made of atoms as well. Alternative conceptions on matter (Liu, 2001) found that outstanding issues remain on matter concept development from elementary to high school.

Bonding

Previous research has identified a range of difficulties with understanding ionic bonding (Butts & Smith, 1987; Boo, 1998). Taber (1997) believed that students adopted a molecular framework for ionic bonding because they considered sodium chloride as a molecular solid similar to iodine, consisting of discrete units, each unit is made up of a sodium ion and a chloride ion. Taber (1998a, 1999b) argued that students’ use of the octet rule forms the basis of an alternative conceptual framework for understanding chemical bonding. He believed that this octet rule framework explains why students see bond types as a dichotomy, believe in ionic molecules and “consider ‘proper bonds’ and ‘just forces’ to be ontologically distinct rather than just different in magnitude” (Taber, 1998a, p. 606). It is likely that these alternative conceptions arise due to similar methods of teaching and/or presentation of content in textbooks (Taber, 1997; Tan & Treagust, 1999) as students only encounter ideas about bonding during formal instruction. For example, some students thought that an electrical current in metals was produced by the movement of atoms or ions, while others thought that atoms in metals transferred electricity from one atom to another.

Othman, Treagust and Chandrasegaran (2008) in a study on 260 Grades 9 and 10 students in Singapore reported that students' limited understanding of the particulate nature of matter influenced their understanding of chemical bonding. Coll (2000) found that few Grade 12 students, undergraduates and postgraduates were able to explain bonding in alloys and malleability of metals.

Nicoll (2001) reported that some students' misconceptions relating to bonding are resistant to change despite increased chemistry education. Peterson, Treagust, and Garnett (1989) suggested that the students' alternative conceptions in bonding were due to the students' lack of distinction of meaning of the same words used in a chemistry context and in everyday English speech. Another reason given was the emphasis of teachers and students, due to time and syllabus constraints, on the acquisition of facts rather than the comprehension of concepts. de Prosada (1997) suggested that the lack of understanding of bonding could be due to the way it was presented in textbooks. He found that Spanish textbooks practically only defined metallic bonding with very little explanation, and had confusing diagrams such as those which showed inaccurate proportion of sizes between electrons and other particles. Since students had difficulty in relating the macroscopic properties of metals with the explanations at the microscopic level, they often resorted to rote learning. The research by Birk and Kurtz (1999) in the United States showed that beginning students of chemistry might actually have very little or no conceptions. They suggested that these beginners, for example, high school students, might not be intellectually prepared to deal with such abstract topics, or had poor learning experiences.

Students had difficulties understanding lattices, delocalisation of electrons and the electrical conductivity of graphite. de Posada (1997) and Taber (1998a) found that Grades 10 to 12 had vague conceptions of metallic bonding and how metals conduct electricity. However, these concepts are essential to understanding electrolysis.

Chemical reactions and changes

Ahtee and Varjola (1998) found that many students cannot understand the interactive nature of a chemical reaction, the concept of atoms rearranging and yet retaining

their identity. They believed that understanding chemical reactions requires the ability to differentiate among concepts such as element, compound, and mixture, and atom and molecule. Watson, Prieto and Dillon (1997) reported that students made no mention of atomic or molecular particles in their explanation of chemical reactions, however “students tend to explain chemical phenomena using mostly visual criteria related to macroscopic properties” (Gabel & Bunce, 1994, p. 308).

Studies have shown that students had difficulty in explaining the evaporation, boiling and condensation, and were confused about conservation of matter during phase changes as well as the size, shape, weight, spacing and bonding of molecules in the different phases (Chang, 1999; Fensham, 1994; Griffiths & Preston, 1992; Hatzinikita & Koulaidis, 1997; Lee et al., 1993; Nakhleh, 1992; Osborne & Cosgrove, 1983; Skamp, 1999). Many students believed that water had changed into air when it evaporated, that air reacted with cold surfaces to form water upon condensation, and that bubbles formed by boiling water were made of air, oxygen or hydrogen. Ahtee and Varjola (1998) found that nearly 20% of the 7th and 8th graders and 10% of senior secondary school students in their study considered change of state and dissolving to be chemical changes. They suggested that this was because students were introduced to many reactions which involved ‘change of state’ such as the formation of precipitate or gas, and perhaps, disappearance of solids.

Johnson (2002) examined the use of the ideas of elements, compounds and the bonding between atoms to explain chemical change and the intersection of these ideas with basic particle ideas. Evidence was presented which suggests that the particle ideas were the means by which the students came to acknowledge the phenomenon of chemical change, having been unmoved by a macroscopic approach which identified substances by melting and boiling point. Nakhleh et al. (2005) focussed on students’ understandings of the macroscopic and microscopic properties of the common states of matter (solids, liquids, and gases), as well as their understandings of changes of state and dissolving.

Redox

Many students find redox difficult and are confused with the existence of four different models of redox (Harrison & Treagust, 1998). Ringnes (1995) believed that the way redox is taught in school does not promote understanding because students are taught four different definitions of redox, the chemical terms used are in conflict with their everyday usage, and the historical development of the concepts are seldom given. Researchers (Garnett et al., 1990; Ringnes, 1995) believed that the oxidation number model helps students most in understanding and identifying redox reactions. Nevertheless, De Jong et al. (1995) argued that the concept of oxidation number is difficult to teach, and recommended that teachers omit teaching the concept of oxidation number because “core electrochemical concepts and procedures can be taught without oxidation numbers” (p. 1109).

Confusion may arise with the everyday use of terms. For instance, “to reduce means to gain (electrons), contrasting to decrease in everyday language, and oxidations need not comprise reactions with oxygen” (Ringnes, 1995, p. 77). Schmidt (1997) reported that many students are misled by the ‘ox’ in ‘redox’ into thinking that oxygen must be involved in any redox reactions. Linguistic complexity such as ‘the oxidant is reduced’ and the ‘reductant is oxidised’ also appeared to cause student confusion (De Jong et al., 1995). De Jong and Treagust (2002) reported that in redox reactions, the conceptual difficulties include mutual dependence of oxidation and reduction reactions; the process of transfer of electrons; the meaning and assigning of oxidation numbers. The procedural difficulties include identifying reactants as oxidizing or reducing agents; identifying reaction equations as oxidation-reduction equations; and balancing complex redox equations. Redox reactions are the major reactions that take place at the electrodes in electrolysis and electrochemical cells.

METHODOLOGIES RELATED TO THE RESEARCH

Interviews, concept mapping, multiple choice tests, and identification of concepts and propositional knowledge statements were used to identify students’ conceptions of electrolysis.

Interviews

Interviews can be carried out to probe students' understanding using the interview-about-instances or interview-about-events. The interview-about-instances procedure uses a set of stimuli, most often cards with pictures and a small amount of writing. The interview begins with a request for the interviewee to respond with his or her own understanding of a focus concept by discussing the cards as they are revealed successfully (Carr, 1996). As for the interview-about-events, it is similar to the former, except that the stimulus is some activity carried out with the student. These interview methods (Carr, 1996; Osborne & Gilbert, 1980; Rye & Rubba, 1998; White & Gunstone, 1992) are very useful for exposing the nature of students' understanding and possible alternative conceptions.

Cohen, Manion and Morrison (2007) and Anderson (2000) promoted the use of interview in collecting data as interview allows the in-depth analysis and pursuit of details. Interviews can be structured, semi-structured or unstructured. In a structured interview, a series of questions, called a protocol, is prepared prior to the interview, and the interviewer has to follow rigidly the series of questions. The interview allows the interviewer to probe the interviewee's ideas in as much detail as desired (Taber, 1998b). However, as Duit et al. (1996) pointed out, much experience is needed to carry out interviews effectively and much background knowledge is needed to make valid interpretations of students' responses. Thus classroom teachers are not likely to conduct individual interviews, especially because they have limited time and high enrolments (Treagust, 1995). Markow and Lonning (1998) noted that if the interviewer is also the teacher of the interviewee, the interviewee may be reluctant to voice negative opinions. Recent research in chemistry education (Boz & Uzuntiryaki, 2006; Dalgety, Coll & Jones, 2003; Gomez, et al., 2006; Liu & Lesniak, 2006; Nakhleh et al., 2005; Stains & Talanquer, 2007) used the interview method to elicit information from their respondents.

Concept mapping

Concept mapping is one approach to encourage meaningful learning. Novak and Gowin (1984) stated that concept maps should be hierarchical, with the more general

concepts at the top of the map with progressively more specific and less inclusive concepts arranged below. Related concepts are then linked by words describing the relationship between the concepts. A concept map aims to show how someone sees the relations between ideas, things or people (White & Gunstone, 1992, p.15). The main idea of concept mapping is that students do their own constructing of the concepts and their relationships. Concept maps focus more specifically on the structure and linking that the student perceives, and have been useful in helping students and/or their teachers recognise and modify faulty knowledge structures. The construction of a concept map by a group of students encourages discussion and reflection, and this contributes to meaningful learning (White & Gunstone, 1992). Students' language ability is important for concept mapping as without the appropriate vocabulary, the students may not be able to express their ideas logically (Kinchin, 2000). Concept mapping is seen as a tool (Kinchin, 2000) that may support learning within an appropriate teaching environment. In a study on two classes of tenth grade students in a Turkish high school, Ozmen, Demircioglu, and Coll (2007) found that concept mapping in conjunction with laboratory activities is viewed as being more enjoyable, helps student link concepts, and reduces their alternative conceptions.

Recent research (Hoz, Bowman & Chacham, 1997; Rye & Rubba, 1998; Zele, Lenaerts, & Wieme, 2004) made use of concept mapping. "Concept mapping theory and research indicate concept maps are appropriate tools to assist with communication, easy to use, and are seen as beneficial by their users" (Freeman & Jessup, 2004, p. 151). This is supported by Brandt, et al. (2001) and Derbentseva, Safayeni and Canas (2007). Brandt, et al. (2001) found a significant positive effect of extra attention to visualization on the learning achievement of students in electrochemistry while Derbentseva, et al. (2007) reported that concept map construction task increased dynamic thinking.

Multiple choice tests

Multiple choice tests have the advantage that the results obtained are easily processed and analysed (Peterson, Treagust, & Garnett, 1989; Taber, 1999a; Tan & Treagust, 1999). Researchers (Griffard & Wandersee, 2001; Peterson et al., 1989;

Taber, 1997, 1999a; Voska & Heikkinen, 2000) have used multiple choice tests to determine students' conceptions in science. Treagust (1986, 1988, 1995) and Tamir (1990) stated that the development of multiple choice tests based on student conceptions has the potential to make a valuable contribution to the body of work in the area of students' conceptions, and to enable classroom teachers to more readily use the findings of research in their lessons. Ben-Zvi and Hofstein (1996) believed that research in student conceptions has had only limited impact on teaching and learning in schools, one of the reasons being teachers' lack of awareness of the learning difficulties and alternative conceptions that exist among their students. Thus teachers could use such tests as a tool to diagnose student conceptions, and steps could then be taken to help students see that the science concepts make more sense than their own conceptions, hence increasing the status of science concepts (Hewson, 1996).

Treagust (1995) described how two-tier multiple choice diagnostic instruments can identify and be used to evaluate student conceptions in specific content areas; the first-tier choices examine factual knowledge while the second-tier choices examine the reasons behind the first-tier choice. To ensure the validity of the diagnostic instrument, the propositional knowledge is to be specified clearly. The items in the instrument are to be developed based on known student conceptions, student-drawn concept maps and responses from students to interviews and free response items. This methodology has been used to develop diagnostic tests on photosynthesis and respiration (Haslam & Treagust, 1987), and diffusion and osmosis (Odom & Barrow, 1995) in Biology. In chemistry, diagnostic instruments were developed for covalent bonding (Peterson, 1986; Peterson & Treagust, 1989; Peterson et al., 1989), chemical bonding (Tan, 1994; Tan & Treagust, 1999), and chemical equilibrium (Tyson, Treagust & Bucat, 1999). The instrument on covalent bonding (Peterson, 1986; Peterson & Treagust, 1989; Peterson et al., 1989) was used by Goh, Khoo and Chia (1993) in a cross-cultural comparison between Australian and Singaporean students, and in a cross-age study by Birk and Kurtz (1999) to determine the retention of specific misconception over time, as well as the extent to which students consistently hold misconceptions. Voska and Heikkinen (2000) noted that the justification of using two-tier tests with free response or a two-tier multiple choice test, depends on the goal of the researcher or teacher in using the test.

In recent years, two-tiered tests are used to identify scientific conceptions of students in the Taiwan National Science Concept Learning Study (Chiu, 2007; Treagust & Chandrasegaran, 2007; Tsai, Chen, Chou & Lain, 2007). As an alternative to diagnostic testing, the Taiwanese two-tiered tests were designed to identify the scientific conceptions of students using a large national random sample similar to data collecting procedures in Trends in Mathematics and Science Studies (TIMSS) and PISA. The Taiwanese study gauged students' performance from elementary to senior high school and compared male and female students.

Rasch Model can also be utilized as an alternative tool for the development, modification and monitoring of valid measurement instruments. Boone and Scantlebury (2006) highlighted the advantages of using the Rasch model which allows researchers to confidently compare results over time. When applied to multiple-choice science tests, the Rasch model also determines the item difficulty independent of the test takers, and the student's ability independent of test items.

ELECTROCHEMISTRY

De Jong and Treagust (2002) found that electrochemistry is ranked by teachers and students as one of the most difficult curriculum domains taught and learnt in secondary school chemistry. They also found that the number of empirical studies of students' conceptions and learning difficulties concerning electrochemistry is rather limited when compared with studies concerning many other chemistry topics. Broadly, there are two main topics of redox reactions and electrochemical cells. In electrochemical cells, five studies dealing with teaching and learning electrochemical cells (Barral, Fernandez, & Otero, 1992; De Jong & Acampo, 1996; Garnett & Treagust, 1992b; Ogude & Bradley, 1994; Sanger & Greenbowe, 1997a, 1999) led to the identification of seven main areas of difficulties. These difficulties are divided into conceptual and procedural difficulties (De Jong & Treagust, 2002). Conceptual difficulties include conduction in the electrolyte; charge on the anode and the cathode in galvanic cells; and the need for a standard half-cell. The procedural difficulties include identifying the anode and the cathode; predicting the products and the magnitude of potential differences of galvanic cells; and predicting the products of electrolysis. After reviewing the literature on the teaching and learning

of electrochemistry, De Jong and Treagust (2002) recommended that teachers should “develop their knowledge of students’ alternative conceptions of electrochemical phenomena and students’ difficulties in understanding these phenomena” (p. 335).

Huddle et al. (2000) reported that school students, college students, and preservice teachers in South Africa have all manifested similar erroneous conceptions in electrochemistry as found by Garnett and Treagust (1992b) and Sanger and Greenbowe (1997a) in studies of Australian and American students, respectively. Students’ misconceptions about the flow of electrons are described as “electrons move through solution by being attracted from one ion to another” (Garnett & Treagust, 1992a, p.131). Some students in the study explained that because the anode is negatively charged, so it attracts cations (Garnett & Treagust, 1992b). Another misconception reported by Sanger and Greenbowe (1997a) is “Electrons are transferred from cathode to anode by the ions in the solution” (p. 820). Ogude and Bradley (1996) also reported that “.....the common error was that during electrolysis, an electric current breaks the electrolyte into positive and negative ions” (p. 1148). Huddle et al. (2000) found that using a teaching model to teach electrochemistry “led to a significant improvement in the students’ understanding of what was occurring at the microscopic level in an electrochemical cell and helped to address known alternate conceptions” (p. 109) .

Ozkaya (2002) studied how prospective teachers studying at the university understand difficult electrochemical concepts such as cell potential and equilibrium in galvanic cells. In a study of 64 high school students in Turkey, Yuruk (2007) used a 23-item multiple choice test to assess students’ conceptual understanding of electrochemical cells; the research showed conceptual change texts can be used as a cost- and resource- effective supplement to classroom instruction to promote students’ understanding electrochemical concepts. Similarly, in a study on 57 10th grade high school students at a public school in Venezuela, Niaz and Chacon (2003) concluded that the teaching experiments facilitated students’ understanding (progressive transitions) of electrochemistry. The goal of the first teaching experiment was to determine how many amperes are required to deposit all the Bismuth (Bi) present in 400mL of a 0.4 mol/L solution of BiCl₃, if the current circulates for 30 minutes. The second experiment was: A current of 0.06 A

electrolysed for 12 min and deposited part of the copper present in 250 mL of a 0.1 mol/L solution of CuSO_4 . Calculate (a) the mass of Cu deposited; (b) concentration in mol/L of the new solution.

Yochum and Luoma (1995) explained that students find electrochemistry difficult to master because “they cannot observe or imagine what happens in the microscopic level in an electrochemical reaction” (Yochum & Luoma, 1995, p. 55). They carried out two demonstrations, Part A and Part B to illustrate their point.

Part A: In the classical demonstration, students were shown three reactions. First, zinc was placed in dilute hydrochloric acid. Students observed the evolution of bubbles, hydrogen gas, at the surface of the zinc. Second, copper was placed in dilute hydrochloric acid. Students observed that no gas evolved at the surface of the copper. Lastly, the zinc and copper were connected and placed in dilute hydrochloric acid. Students observed the discrepant event. Bubbles of hydrogen gas evolved from the zinc and the copper.

Part B: In order to aid students in mentally visualizing the electrochemical concepts demonstrated, Yochum and Luoma (1995) developed a computer animation video that modeled the microscopic events. In viewing this animation video, students gained a visually concrete model of these microscopic processes and enabling them to improve their own mental models. Yochum and Luoma (1995) concluded that multi-media is the audience’s preferred augmentation method for visualizing events on both the macroscopic and microscopic levels.

Not only students have alternative conceptions on electric current, teachers also hold alternative conceptions (Pardhan & Bano, 2001; Stocklmayer & Treagust, 1996). In a study by Pardhan and Bano (2001) which was designed to identify the nature and origin of the alternative conceptions on science teachers, it was found that 67% of the teachers agreed that the electric current flows from the positive terminal of a dry cell to the negative terminal of it. In the scientific view, the direction of current flow in the external circuit is from the cell’s positive terminal to the negative terminal. Similarly, in another study of 1,678 ninth-grade Turkish students, Sencar and Eryilmaz (2004) also reported misconceptions among students in interpreting electric

circuits. Lee (2007) focused on primary school students' alternative conceptions pertaining to batteries and found that many alternate conceptions are related to language and daily life in Taiwan. For example, a student had the alternate conception that a battery contains water. This is because in Mandarin, which is the popular language in Taiwan, the term "battery" is translated as "electricity pond". The student used an intuitive analogy to assume the correlation between pond and water, thus leading to the alternate conception.

Masrukin (2002) agreed with the work of De Jong and Treagust (2002) discussed earlier. Masrukin (2002) reported that a student needs to understand the following preconceptions before embarking into the topic of electrochemistry: how ions are formed and the formula and charge of ions; the atomic structure of atoms; the electronic configuration of atoms and ions; the particulate nature of matter and its transformation; writing a balanced equation; ionic dissociation; the electrochemical series; the concept of redox; the difference between electrolytes and non-electrolytes; and the concept of electricity.

In a study on 15,700 subjects Schmidt et al. (2007) identified secondary-school students' problems in learning electrochemistry at an introductory chemistry level. The research found that "students based their reasoning on four alternative concepts: (a) During electrolysis, the electric current produces ions; (b) electrons migrate through the solution from one electrode to the other; (c) the cathode is always the minus pole, the anode the plus pole; and (d) the plus and minus poles carry charges" (p. 258).

ENVIRONMENTAL ISSUES

The recent report of 100 children recorded with high levels of lead and 4000 birds dying of heavy-metal contamination in Esperance, Western Australia (Towie, 2008) is an example of a recent environmental issue related to chemicals. Yencken (2000, pp. 24-25) as cited in Gough (2002, p.1221) reported that the environmental problems now facing the world are global problems stemming from the process of industrialization and capitalist development that has been taking place in every country, albeit at different speeds and intensities.

Yilmaz, Boone and Andersen (2004) found that results of ANOVA analyses in a study of Turkish students indicated that recent high achievement in science courses resulted in more positive attitudes toward environmental issues. They also reported that higher achievement is associated with higher socio-economical background. In another study, Gilbert, Treagust and Gobert (2003) reported that environmental education has become steadily more significant. Similarly Dillon (2002) cautioned critical issues that characterize the interfaces between science education and environmental education at the turn of the century. According to him, environmental education “provides an opportunity to bring in modern and challenging social and scientific issues into the classroom that is currently hindered by the packed and conservative science curricula of many countries around the world” (Dillon, 2002, p. 1112). Given the on-going resistances to environmental education in schools, the static nature of science education practices, and declining student interest in studying science subject, Gough (2002) proposed that for achieving sustainable development, science education must have a role in encouraging ecological thinking.

CONFIDENCE AND ATTITUDES

The terms ‘confidence’ and ‘self-efficacy’ have been used interchangeably in many studies (Appleton & Kindt, 2002; Rice & Roychoudhury, 2003; Settlage, 2000; Watters & Ginns, 2000). In this study the same approach is used. Bandura defined ‘self-efficacy’ as “beliefs in one’s capabilities to organize and execute the courses of action required to produce given attainments” (Bandura, 1997, p. 3). Self-efficacy is composed of two components: efficacy expectation and response-outcome expectation. Bandura (1997) also put forward four main sources of efficacy information: enactive mastery experiences, vicarious experiences, verbal persuasion, and physiological and affective states. Enactive mastery experiences refer to successes with particular situations that require persistent effort in overcoming difficulties, and are indicators of capability. Bandura (1997) considered enactive mastery experiences to be the most influential source of self-efficacy as they provide the most authentic evidence of success. The second source of efficacy information is vicarious experiences which are situations where people estimate their capabilities in comparison to others who have modeled the desired behaviour. Self-efficacy can be enhanced when individuals perceive themselves as capable of performing favourably

in comparison to others. Verbal or social persuasion refers to situations where individuals are given positive evaluative feedback from other people whose opinions are valued. The fourth source of efficacy information is physiological and affective states, which refers to an individual's response to their own stress, fear and anxiety (Palmer, 2006).

Self-efficacy has been found to be an accurate predictor of performance. People with low self-efficacy about an activity will tend to avoid that activity, whereas people with high self-efficacy will make vigorous and persistent efforts and be more likely to complete the task successfully (Palmer, 2001).

In a study of 73 preservice primary teachers enrolled in a second-year science education unit at an Australian university, Howitt (2007) found that challenging preservice teachers' perceptions of science and science teaching was an important means of increasing their confidence and attitudes towards science and science teaching. Showing preservice teachers what primary science 'looks like' allowed them to view science in a simpler and more subtle, informal, creative and enjoyable manner than they had experienced before. Besides this, "learning experiences situated with meaningful and authentic contexts also have contributed to increased confidence of preservice teachers" (Howitt, 2007, p. 34). The six factors that were considered important influences on the preservice teachers' confidence and attitudes towards science: developing students' pedagogical content knowledge, fostering more positive interactions between the science educator and the preservice teacher, developing a positive learning environment, encouraging deeper reflection, providing more relevant assessment, and encouraging science teaching during the preservice teachers' school placement. Howitt (2007) stated that all six factors of the science methods course were found to be important in influencing the preservice teachers' confidence towards science and science teaching and no single factor was perceived to be a major contributor to the preservice teachers' confidence.

In another study on the implementation of English for the teaching of mathematics and science (ETeMS) policy in Malaysia (MOE, Malaysia and MOE, Thailand, 2008), it was found that teachers' attributes such as the level of readiness and confidence were critical success factors. Urban school teachers were found to have a

higher level of readiness compared to those from rural schools; however, primary school teachers had a higher level of confidence compared to secondary school teachers. The training of ETeMS teachers had a moderate effect on the programme itself. This study recommended continuous monitoring of the implementation of EteMS and a need to streamline and improve the training of teachers.

Dalgety, et al. (2003) developed an instrument and conducted a study with 669 first-year chemistry university students on their attitude toward chemistry, chemistry self-efficacy, and learning experiences. They reported that during high school, students develop attitudes and efficacy beliefs toward chemistry that they bring to their tertiary-level studies. In a similar vein, Chan and Mousley's (2005) study in a Malaysian private college involved data on students' achievements, interest levels, beliefs and attitudes and mathematical performance from 290 students. Most of the students in this project felt "a need to practice sufficient examples before they developed adequate confidence and curiosity for more independent and diverse ways of solving problems" (Chan & Mousley, 2005, p. 223).

Science Self-efficacy

Studies of student science self-efficacy, which refers to the students' perception of ability to undertake science tasks, are relatively few (Dalgety & Coll, 2006; Pearson, 2008) in comparison with studies on mathematics self-efficacy (Gainor & Lent, 1998; Lent, Lopez & Bieschke, 1991; Lent, Lopez, Brown & Gore, 1996), and preservice science teachers' science self-efficacy (Howitt, 2007; de Laat & Walters, 1995; Ramey-Gassert, Shroyer & Staver, 1996). Dalgety and Coll (2006) is the only study on chemistry self-efficacy; Pearson's (2008) study dealt with the self-efficacy of science classes of grade 2-5 elementary students who were studying science.

Science self-efficacy has been reported to be influenced by factors such as school learning environments, students' attitude towards science, and students' science achievement. For example, Tymms' (1997) study of science in primary schools found that science self-efficacy was related to individual school variables. Both Tymms (1997) and Lorschach and Jinks (1999) suggest findings such as these may be related to the student's learning environments. According to the literature; science

self-efficacy is also influenced by student attitude-towards-science (Jones & Young, 1995). Some studies suggest that science self-efficacy is related to science achievement; and as might be expected, students who have greater science self-efficacy achieve higher grades in science, and have greater motivation to achieve in science (Rowe, 1998; Williams, 1994). Nauta, Epperson and Waggoner (1999) reported that students with high self-efficacy often attributed their success to effort, and thus were more likely to persist in science. Similarly, Lapan, Shaughnessy and Boggs (1996) found that self-efficacy mediated the relationship between achievement and interest in that achievement in science lead to higher science self-efficacy, which in turn served to strengthen students' academic goals.

Dalgety and Coll (2006) examined the changes in chemistry students' chemistry self-efficacy throughout their first year of chemistry study at a New Zealand university. Chemistry self-efficacy was measured at three times throughout the year using the self-efficacy component of the Chemistry Attitudes and Experiences Questionnaire (CAEQ). Quantitative data were triangulated with qualitative data obtained from interviews of a cohort of 19 students. The findings suggested that chemistry self-efficacy is cyclical in that student with high self-efficacy are more confident and as a consequence less likely to suffer setbacks academically. Zimmerman (1995) reported that "if students believe they lack the capability to master academic demands, they will tend to avoid them even though the outcomes are academically achievable" (p. 217).

ANALYSIS OF TEXTBOOKS

This section focuses on studies carried out on analysis of textbooks to provide more details into how textbooks and workbooks influence the teaching and learning of electrolysis in Malaysia. Textbooks play a dominant role in science education as they are often the sole source of information on the subject for both teachers and students, and influence the curriculum, coverage of content and teaching approaches (Chiang-Soong & Yager, 1993; De Jong et al., 1995; Sanger & Greenbowe, 1997a, 1999; Tan, 2000). Chiu (2007) reported that for high school students, instruction, textbooks, and teaching materials were the main sources of student conceptions.

Nevertheless, textbook learning should be “meaningful, conceptually integrated, and active” (de Posada, 1999, p. 427). Hence textbook content should be free from ambiguities and alternative conceptions, should present and explain information, help students to relate new material to what has already been learnt, and help students to integrate the material presented explicitly in a coherent way (Tan, 2000).

Textbooks have been analysed as sources of alternative conceptions (Chiu, 2007; Cho et al., 1985; Pardhan & Bano, 2001; Sanger & Greenbowe, 1999) and for the use of analogy (Curtis & Reigeluth, 1984; Orgill & Bodner, 2006; Thiele, Venville & Treagust, 1995; Tsai et al., 2007). Treatment of topics and concepts have also been analysed (de Berg & Treagust, 1993; de Berg & Greive, 1999; de Posada, 1999; Palmer & Treagust, 1996; Shiland, 1997). For example eight chemistry textbooks were analysed by Shiland (1997) pertaining to quantum mechanics on four elements, namely dissatisfaction, intelligibility, plausibility and fruitfulness, associated with a conceptual change model. He found the four elements were not present in sufficient quantities to encourage students to accept quantum mechanics over the simpler Bohr model. de Berg and Treagust (1993) analysed fourteen chemistry textbooks used in Australian schools to determine the extent to which qualitative discussion and exercises, as well as qualitative-to-quantitative sequences were used in the textbooks. They found minimal qualitative treatment of the gas laws.

Textbooks also have been analysed to determine the treatment of other issues of science literacy and goals of science education (Chiang-Soong & Yager, 1993; Wilkinson, 1999). For instance, Chiang-Soong and Yager (1993) reported that students expected the textbook to be the main source of classroom information, and parents expressed concern if textbooks were not issued.

Boulabiar, Bouraoui, Chastrette, and Adberrabba (2004) analysed chemistry textbooks to see how electrochemistry, particularly the Daniell cell, is presented in secondary schools in France and Tunisia. Analysis of several important studies on students’ misconceptions in electrochemistry shows that students have trouble in understanding ionic conduction and the structure of solutions. They found that the separation between the two solutions and the presence of the salt bridge, although useful for presenting redox reactions, tends to reinforce misconceptions. In their

studies on other research articles, Boulabiar et al. (2004) also proposed that the use of diagnostic tests on the nature of current would be useful. Ten college-level chemistry texts were analysed by Sanger and Greenbowe (1999) for statements or drawings that could lead to alternative conceptions in electrochemistry. They found that many illustrations and statements used in the textbooks could be misinterpreted by students. Examples include the use of vague or misleading terms such as ‘ionic charge carriers’ and always drawing the anode as the left-hand half-cell. Garnett et al. (1990) and Ogude and Bradley (1994) suggested that a major source of student misconceptions comes from imprecise or inappropriate language used by textbooks in explaining electrochemical concepts. Sanger and Greenbowe (1997a) revealed that two of the textbooks used by the students have statements suggesting the electrodes in electrochemical cells are charged.

The most effective use of analogies is as an advance organizer to enable students to link new knowledge (Curtis & Reigeluth, 1984) and as an embedded activator to explain preceding information and introduce subsequent material. Orgill and Bodner (2006) analysed the use of analogies in eight biochemistry textbooks. They found that although textbook authors use a significant number of analogies as learning aids in each of their textbooks, “none of the analogies are completely explained” (p. 1059). Previously, in analysing analogies in four biology and ten chemistry textbooks, Thiele et al. (1995) found that the biology and chemistry textbooks had similar proportions of structural and functional type analogies, but chemistry textbooks had less pictorial but more verbal analogies. Harrison and Treagust (1998) reported that most of the textbooks they examined failed to warn readers that analogies or models are “human inventions that break down at some point” (p. 424).

SUMMARY

In the first part of the literature review, the nature of learning was discussed. This was followed by the nature of alternative conceptions, studies of students’ conceptions in chemistry, and methodologies for investigating students’ conceptions. The following points refer to this study:

- Consistent with the theories of Piaget and Ausubel, learning is viewed as the construction of personal meaning (Tytler, 2002a)
- Contextualising science instruction involves utilizing students' prior knowledge and everyday experiences as a catalyst for understanding challenging science concepts (Rivet & Krajcik, 2008)
- Children develop ideas and beliefs about the natural world and through their everyday life experiences (Duit & Treagust, 1995)
- Students have various conceptions about science concepts that vary from scientific conceptions (Duit, 2009; Novak, 1983, 1993; Tytler, 2002a; Wandersee et al., 1994)
- The difficulties that students have in learning chemistry and students' conceptions of the particulate nature of matter, chemical bonding, chemical reactions and changes, redox, and electrochemistry based on past research carried out by different researchers, provided the framework for the researcher in this study.
- Methodologies related to the research included interviews, concept mapping, and multiple choice tests.

The literature reviewed provided the theoretical and methodological framework for the development of the two-tier multiple choice diagnostic instrument on electrolysis, which is described in Chapters 3, 5 and 6, and the use of the diagnostic instrument to study the students' understanding of electrolysis which is described in Chapter 7. The review on confidence and attitude provided the guidelines for establishing a relationship between the students' correct answers and their level of confidence. The section on the roles and analyses of textbooks provided the framework for Chapter 4 which deals with the analysis of three textbooks on electrolysis. Finally, the literature on electrochemistry provided reasons why students find electrolysis difficult and guided the recommendations which are described in Chapter 8.

CHAPTER THREE

IDENTIFICATION OF CONCEPTS AND PROPOSITIONAL KNOWLEDGE STATEMENTS

INTRODUCTION

The focus of this chapter is on Research Question 1 which seeks to describe the development of the content framework in order to identify the concepts and propositional knowledge necessary for secondary chemistry students to understand the topic of electrolysis. This is the first phase in the development of a multiple choice diagnostic instrument as outlined by Treagust (1986, 1988, 1995). A concept map and a list of propositional knowledge statements were prepared as required for students who are preparing for Malaysia School Certificate chemistry examinations.

IDENTIFICATION OF SUBJECT CONTENT

Four procedures were used to limit and specify the subject content related to the topic electrolysis:

1. Extract the relevant sections of the Malaysian School Certificate chemistry syllabus for 2008 pertaining to electrolysis,
2. Develop a concept map on electrolysis,
3. Identify the propositional knowledge needed to understand the topic of electrolysis,
4. Relate the propositional knowledge to the concept map.

These four steps were necessary to ensure that the content and hence the development of the two-tier multiple choice items was based on the concepts and propositional knowledge which were being taught to the students preparing for the examination.

Two tertiary educators, Mrs. J and Ms K and three senior secondary chemistry teachers, Mrs. F, Mrs. G, and Mrs. H, with a thorough knowledge of the subject

matter reviewed the concept map, propositional knowledge statements, as well as the extract of syllabus to make sure that they meet the requirements of electrolysis in the Malaysian School Certificate chemistry.

EXTRACT OF SYLLABUS PERTAINING TO ELECTROLYSIS

The Malaysian School Certificate syllabus content for electrolysis is listed under electrochemistry. This topic is meant to be taught in Form Four in the second semester of the year. The syllabus which is given in Appendix A encompasses the meaning of electrolyte and electrical conductivity. In the electrolysis of both molten compounds and aqueous solutions, students are required to identify the cations and anions; describe the electrolytic process; write half equations for the discharge of ions at the anode and cathode; and predict the products from the electrolysis of other molten compounds or aqueous solutions. Students are also required to understand the three factors determining the selective discharge of ions at the electrodes based on position of ions in the electrochemical series; the concentration of ions in a solution; and types of electrodes. The final section in electrolysis covers the electrolysis in industry, the purification and electroplating of metals, the benefits and harmful effects of electrolysis in industries.

Comment:

The use of E^0 values (standard reduction potential) is not taught in Form Four and Form Five. In the General Certificate Examination O-level (in the UK and Singapore) and the equivalent Malaysian syllabuses, the electrochemical series is constructed using dilute aqueous solutions, often in the region of about 0.01M, and it does not include the reduction of water. The electrochemical series used at school level in the Malaysian (Eng, Lim & Lim, 2007; Loh & Tan, 2006; Prescott, 2003) and UK O-level context (Harwood, 2004; Neuss, 2007) is different from the tertiary level (Becker, 2000; Blackman, Bottle, Schmid, Mocerino & Wille, 2008). Becker (2000) also cautioned the use of E^0 to predict what gets oxidised or reduced:

“Often the E^0 values used in predicting the products are based on the assumption that standard state concentrations are present. If concentrations are different from standard state concentrations, E^0 values may not be reliable predictors of what gets oxidised or reduced.” (p. 464)

The arrangement of ions in dilute aqueous solutions in the electrochemical series (Eng, et al., 2007; Loh & Tan, 2006) used in this study is as shown in Figure 3.1.

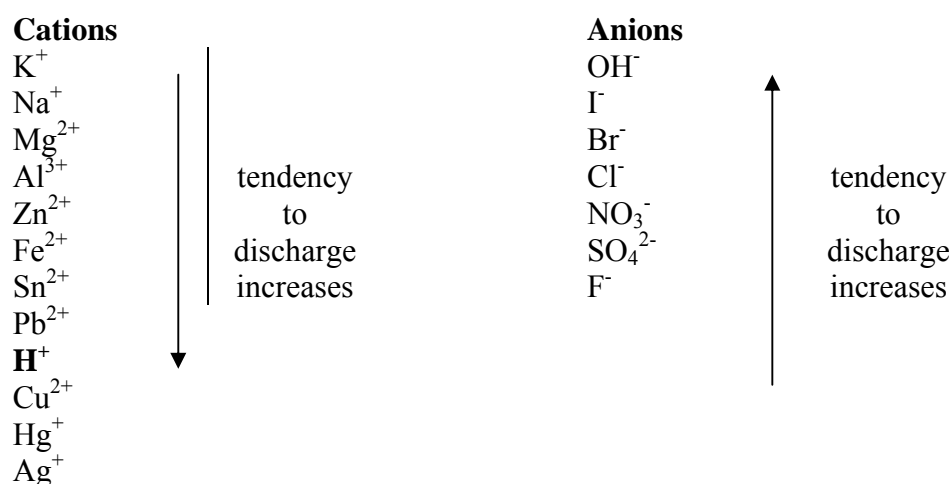


Figure 3.1 The arrangement of ions in the electrochemical series

THE CONCEPT MAP

The concept map was prepared to provide a representation of the relationships between the concepts and the understanding acquired by the students after they have been taught on the topic. The procedures described by Novak and Gowin (1984) were used in developing the concept map. The more general and more-inclusive concepts are at the top of the map, and the more specific and less inclusive concepts arranged below in a hierarchical order. Related concepts are then linked using words to describe their relationships.

The first concept map (Appendix B1) that the author produced showed the electrodes and the cell/battery but they had nothing in common. Mrs. J suggested that there should be a linkage between the two to indicate that the electrode that is connected to the positive terminal of the battery is called the anode, likewise for the cathode. Ms J remarked that the examples for the applications in industry should be brought to the lower level. Mrs. F suggested that an example should be given for the pollution problem. These points were taken into consideration, the concept map was redrawn and revised several times. The final version of the concept map is given in Figure 3.2.

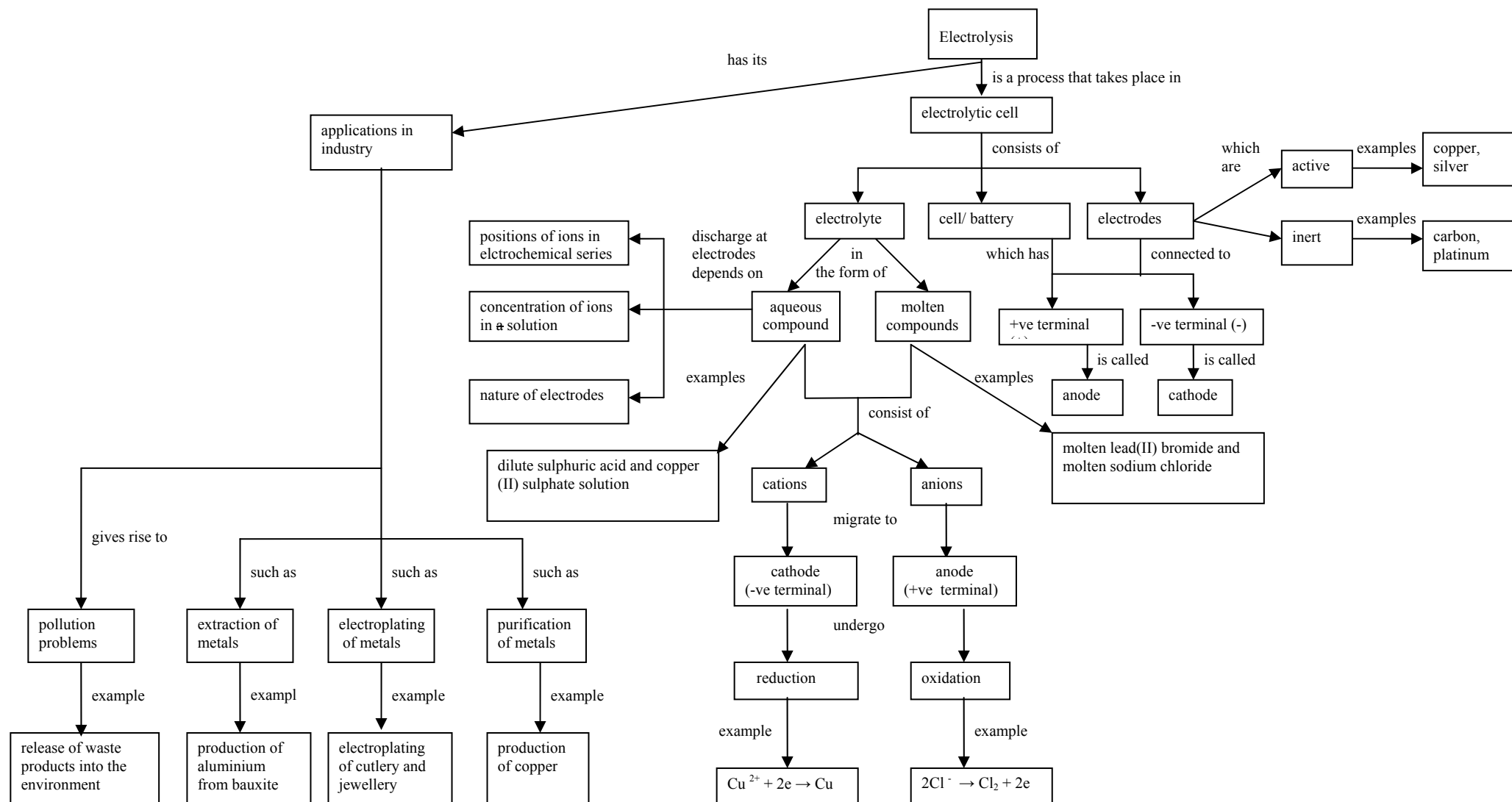


Figure 3.2 Concept map of electrolysis

PROPOSITIONAL KNOWLEDGE STATEMENTS

The propositional knowledge statements were identified from common textbooks used by the students. These statements were written for the content and concepts relevant to the topic on electrolysis. The statements were written at a level of sophistication appropriate to the chemistry students in Form Four. There were 26 propositional knowledge statements in the first draft (Figures 3.3a and 3.3b).

1. Electrolytes are substances that conduct electricity either in the molten state or in aqueous solution, and undergo chemical changes in the process.
2. Non-electrolytes are substances that do not conduct electricity either in the molten state or in aqueous solution.
3. Electrolytes consist of positively charged ions (cations) and negatively charged ions (anions).
4. The electrical conductivity of electrolytes is due to the presence of free moving ions in the electrolytes.
5. Electrolysis is a process in which an electrolyte is decomposed when an electric current passes through it.
6. An electrolytic cell consists of a battery, an electrolyte, and two electrodes.
7. In a complete closed electric circuit, electrons flow from the negative terminal to the positive terminal of the battery.
8. Electrodes are conductors in the form of wires, rods or plates that enable electricity to pass through an electrolyte during electrolysis.
9. Electrodes that do not take part in chemical reactions during electrolysis are known as inert electrodes. Examples are graphite and platinum electrodes.
10. Electrodes that take part in chemical reactions during electrolysis are known as active electrodes. Examples are metal electrodes such as copper and silver.
11. The electrode that is connected to the positive terminal of a battery is called the anode while the electrode that is connected to the negative terminal of a battery is called the cathode.
12. During electrolysis, cations (positive ions) move towards the cathode, the negatively-charged electrode whereas anions (negative ions) move towards the anode, the positively-charged electrode.

Figure 3.3a List of propositional knowledge statements (1-12) developed for the topic of electrolysis

13. Cations are discharged at the cathode by accepting electron(s) from the cathode, whereas anions are discharged at the anode by donating electron(s) to the anode.
14. Reduction occurs at the cathode and oxidation occurs at the anode during electrolysis.
15. Electrolysis of aqueous copper(II) sulphate using inert carbon electrodes will produce copper at the cathode, and oxygen gas at the anode.
16. Electrolysis of dilute sulphuric acid using inert carbon electrodes will produce hydrogen gas at the cathode, and oxygen gas at the anode.
17. The selective discharge of ions depends on the positions of ions in the electrochemical series, the concentration of ions in the electrolyte, and the nature of electrodes used in the electrolysis.
18. The electrochemical series is a list of ions arranged in order of their tendency to be discharged during electrolysis. The lower the position of an ion in the electrochemical series, the higher is the tendency for the ion to be discharged.
19. Industrial applications of electrolysis include extraction, purification, and electroplating of metals.
20. Highly reactive metals can only be extracted from their ores by electrolysis.
21. In the purification of metals using electrolysis, the impure metal is the anode, the pure metal is the cathode, and the electrolyte is an aqueous salt solution of the metal.
22. Electroplating is the process of depositing a layer of metal on another substance using electrolysis.
23. Objects are electroplated to protect them from corrosion and to give them an attractive appearance.
24. To electroplate an object with a metal, the cathode is the object to be plated, the anode is a piece of the pure plating metal and the electrolyte shall contain ions of the plating metal.
25. Electrolysis is an expensive process because it requires a large amount of energy.
26. The industrial use of electrolysis may cause pollution as a result of the production of waste chemicals from the electroplating industry that are released into the environment.

Figure 3.3b List of propositional knowledge statements (13-26) developed for the topic of electrolysis

Changes were made to the original list of propositional knowledge statements to improve the accuracy of the statements required for the understanding by the students. Fifteen additional propositional knowledge statements were needed, six

statements were split up into more statements, some minor word and phrase changes were made to various propositions. None of the original propositions were deleted. The revised list of propositions containing forty one propositional knowledge statements is shown in Figures 3.4a, 3.4b and 3.4c.

1. Electrolytes are substances that conduct electricity either in the molten state or in aqueous solution, and undergo chemical changes in the process.
2. Non-electrolytes are substances that do not conduct electricity either in the molten state or in aqueous solution.
3. The electrical conductivity of electrolytes is due to the presence of free moving ions in the electrolytes.
4. Electrolysis is a process in which an electrolyte is decomposed when an electric current passes through it.
5. An electrolytic cell consists of a battery, an electrolyte, and two electrodes.
6. Electrodes are conductors in the form of wires, rods or plates that enable electricity to pass through an electrolyte during electrolysis.
7. The electrode that is connected to the positive terminal of a battery is called the anode.
8. The electrode that is connected to the negative terminal of a battery is called the cathode.
9. Electrodes that do not take part in chemical reactions during electrolysis are known as inert electrodes.
10. Examples of inert electrodes are carbon (graphite) and platinum electrodes.
11. Electrodes that take part in chemical reactions during electrolysis are known as active electrodes.
12. Examples of active electrodes are metal electrodes such as copper and silver.
13. Electrolytes consist of positively charged ions (cations) and negatively charged ions (anions).
14. In a complete closed electric circuit, electrons flow from the negative terminal to the positive terminal of the battery.
15. During electrolysis, cations (positive ions) move towards the cathode, the negatively-charged electrode whereas anions (negative ions) move towards the anode, the positively-charged electrode.

Figure 3.4a Revised list of propositions and content knowledge statements (1-15) of electrolysis

16. Cations are discharged at the cathode by accepting electron(s) from the cathode, whereas anions are discharged at the anode by donating electron(s) to the anode.
17. In the electrolysis of molten magnesium oxide using carbon electrodes, magnesium is produced at the cathode and oxygen at the anode.
18. In the electrolysis of molten lead(II) bromide using graphite electrodes, lead is produced at the cathode and bromine gas at the anode.
19. Reduction occurs at the cathode and oxidation occurs at the anode during electrolysis.
20. An aqueous solution of a compound is a solution produced when the compound is dissolved in water.
21. An aqueous solution of a compound contains anions and cations of the compound, hydrogen ions, and hydroxide ions from the partial dissociation of water molecules.
22. During electrolysis of an aqueous solution of a compound, two different types of cations move towards the cathode, which are cations of the compound and hydrogen ions.
23. During electrolysis of an aqueous solution of a compound, two different types of anions move towards the anode, which are anions of the compound and hydroxide ions.
24. The selective discharge of ions depends on the positions of ions in the electrochemical series, the concentration of ions in the electrolyte, and the nature of electrodes used in the electrolysis.
25. The electrochemical series is a list of ions arranged in order of their tendency to be discharged during electrolysis. The lower the position of an ion in the electrochemical series, the higher is the tendency for the ion to be discharged.
26. Electrolysis of dilute sulphuric acid using inert carbon electrodes will produce hydrogen gas at the cathode, and oxygen gas at the anode.
27. The concentration of sulphuric acid increases gradually as water is decomposed to hydrogen gas and oxygen gas.
28. Electrolysis of aqueous copper(II) sulphate using inert carbon electrodes will produce copper at the cathode, and oxygen gas at the anode.
29. The aqueous solution of copper (II) sulphate consists of copper(II) ions, sulphate ions, hydrogen ions, and hydroxide ions that move freely.
30. During electrolysis of aqueous solution of copper(II) sulphate, the copper(II) and hydrogen ions move to the cathode. Copper(II) ions are selectively discharged to form copper metal.

Figure 3.4b Revised list of propositions and content knowledge statements (16-30) of electrolysis

31. During electrolysis of aqueous solution of copper(II) sulphate, the sulphate and hydroxide ions move to the anode. The hydroxide ions are selectively discharged to form oxygen and water.
32. The intensity of the blue colour of the electrolyte decreases as the concentration of blue copper(II) ions decreases when more copper is deposited on the cathode.
33. The electrolyte becomes more acidic because of the hydrogen and sulphate ions left.
34. Industrial applications of electrolysis include extraction, purification, and electroplating of metals.
35. Highly reactive metals can only be extracted from their ores by electrolysis.
36. In the purification of metals using electrolysis, the impure metal is the anode, the pure metal is the cathode, and the electrolyte is an aqueous salt solution of the metal.
37. Electroplating is the process of depositing a layer of metal on another substance using electrolysis.
38. Objects are electroplated to protect them from corrosion and to give them an attractive appearance.
39. To electroplate an object with a metal, the cathode is the object to be plated, the anode is a piece of the pure plating metal and the electrolyte shall contain ions of the plating metal.
40. Electrolysis is an expensive process because it requires a large amount of energy.
41. The industrial use of electrolysis may cause pollution as a result of the production of waste chemicals from the electroplating industry that are released into the environment.

Figure 3.4c Revised list of propositions and content knowledge statements (31-41) of electrolysis

RELATING PROPOSITIONAL KNOWLEDGE TO THE CONCEPT MAP

To ensure the list of propositional knowledge statements and the concept map were internally consistent, a matching of the propositional knowledge statements to the concept map was carried out. This matching is shown in Figure 3.5.

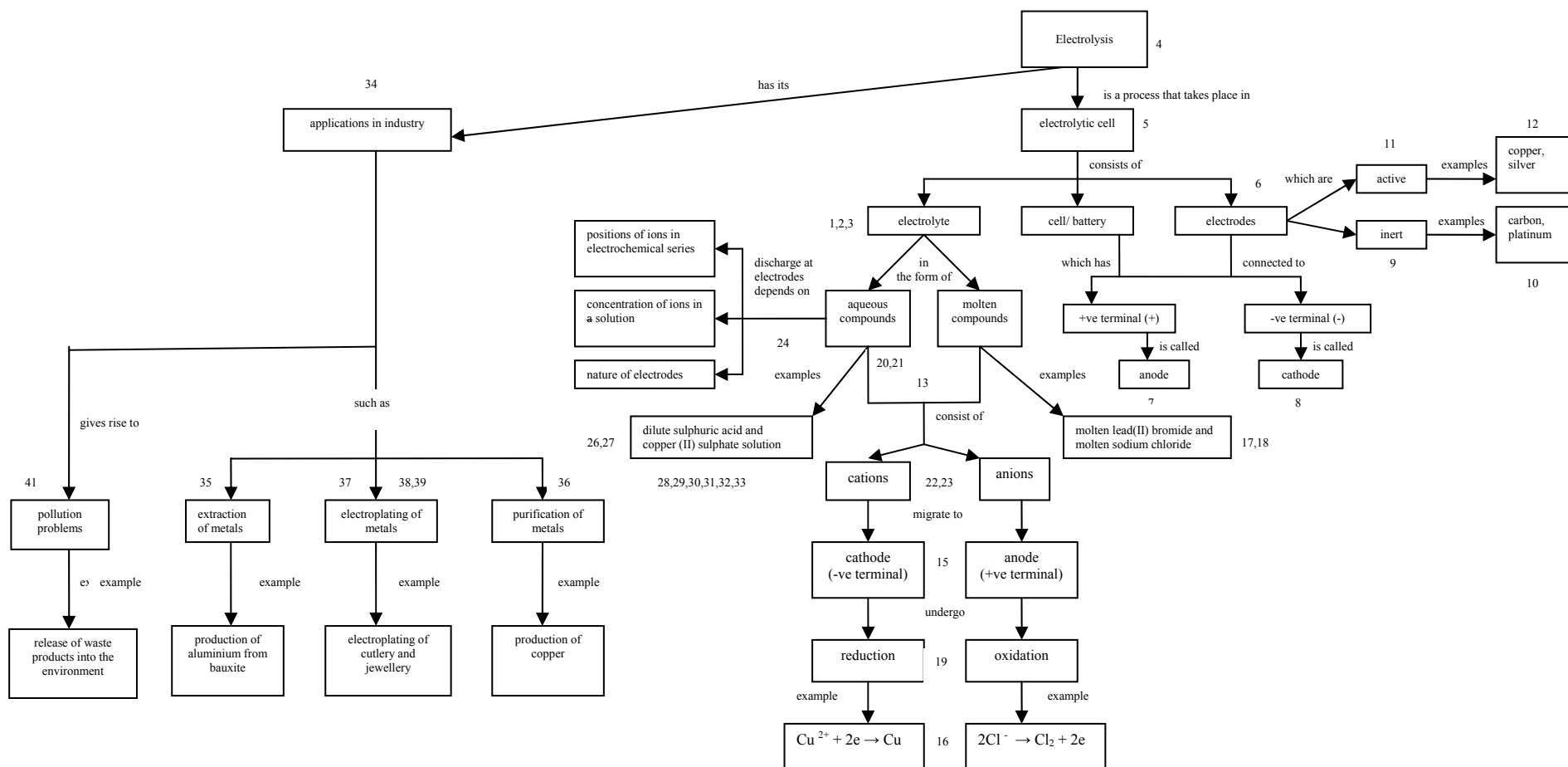


Figure 3.5 Relating propositional knowledge statements to the concept map

SUMMARY

In this chapter, the concepts and propositional knowledge statements that secondary chemistry students need in order to develop an understanding of the topic of electrolysis, were described by an extract of the syllabus, a concept map and a list of propositional statements. A matching of the propositional statements to the concept map was carried out to make sure that they were internally consistent. This chapter has defined the conceptual boundaries of Form Four electrolysis in Malaysia secondary schools, and this has addressed Research Question 1. The development of the two-tier multiple choice diagnostic instrument takes place within these defined conceptual boundaries. Three chemistry textbooks that are used in Malaysia secondary schools are examined in the next chapter to determine if they contain the concepts and propositional knowledge statements necessary for the understanding of electrolysis.

CHAPTER FOUR

ANALYSIS OF TEXTBOOKS

INTRODUCTION

The focus of this chapter is to determine whether the concepts and propositional knowledge present in three widely used textbooks by Form Four students in Malaysia are consistent with the concepts and propositional knowledge identified in Chapter 3 for understanding electrolysis in a meaningful way.

METHOD

Textbooks

Three Form Four level chemistry textbooks were analysed for examples of statements or drawings that could lead to a student misconception in electrolysis. These three textbooks are the major ones used in the secondary schools offering chemistry in Kuching, Malaysia. They are *Focus Super Chemistry* by Eng, et al. (2007), *Exploring Chemistry* by Loh and Tan (2006), and *Chemistry Form 4* by Low, Lim, Eng, Lim, and Ahmad (2005). These textbooks will subsequently be referred to by the authors' initials. For example, *Focus Super Chemistry* will be referred to as ELL, *Exploring Chemistry* as LT, and *Chemistry Form 4* will be referred to as LLELA.

Textbook Analysis

The author made comparisons of the three textbooks by examining the diagrams and content under each of the following titles using a similar approach adopted by Orgill and Bodner (2006). Each textbook was read line by line to look for information the authors used to communicate the electrolysis concepts.

Electrolytes and non-electrolytes

All the three books define electrolytes and non-electrolytes explicitly, with the explanation that electricity is conducted by free mobile ions in electrolytes (ELL, p. 146; LT, p. 158; LLELA, p. 97).

Electron flow in external circuit

Electron flow is not explained in LLELA, but both ELL and LT explained that electrons flow from the anode to the cathode through the connecting wire in the external circuit (ELL, p. 147; LT, p. 165). ELL mentioned it in the main text and also in the diagram, whereas LT mentioned it in the main text (p. 161), and under “Brain power” section with a diagram.

Electrolytic cell

The anode is the electrode connected to the positive terminal of the batteries. Negatively charged ions known as anions in the electrolyte are attracted to the anode whereas the positive ions or cations are attracted to the cathode (ELL, p. 147; LT, p. 161; LLELA, p. 98).

Types of Electrodes

LLELA explained active electrode and inert electrode with examples of each type (p. 101), ELL defined electrode, active electrode, inert electrode, anode and cathode in a table (p. 147), but LT explained inert electrode (p. 161) and did not elaborate on active electrode.

Electrolysis of molten solutions

Identifying cations and anions in a molten solution is explained clearly in LLELA, ELL and LT. In addition, LT has relevant questions for students to work on the formulae of the ions produced in the molten state (p. 165) to check the understanding of students. The migration of cations to the cathode and similarly the anions to the anode are explained clearly with the writing of half equations.

Electrolysis of aqueous solutions

Identifying cations and anions in an aqueous solution is explained clearly in ELL, LT and LLELA. The writing of half equation of discharge of ion is illustrated clearly

with four steps with one example in ELL (p. 150), but LT and LLELA explains it with a general half reaction at the anode and half reaction at the cathode (LT, p. 162; LLELA, p. 100). Selective discharge of ions depending on three factors are well illustrated with examples in all the three books ELL, LT and LLELA (ELL, p.156; LT, p.166-168; LLELA, p. 101).

Extraction of metals

Extraction of reactive metals from their ores with two examples of the extraction of aluminium from molten aluminium oxide and sodium from molten sodium chloride are well explained with diagrams with the electrolytic cell (ELL, p. 159-160; LT, p.176-177) but LLELA explained the extraction of aluminium from molten aluminium oxide only (p. 102).

Purification of metals

In the purification of metals, the impure metal is used as the anode, and the pure metal is used as the cathode (ELL, p. 160; LT, p. 178; LLELA, p. 102). The diagram in LT is more informative, with direction of electron flow in external circuit, and the difference in thickness of the electrodes. This author considers it to be more helpful to show the differences with respect to the electrodes at the beginning of the experiment and after 30 minutes of the experiment as this will help the memory retention power of the students.

Electroplating of metals

All the three books ELL, LT and LLELA give a very clear idea on the substances to be used as the anode, the cathode and the electrolyte in the process of electroplating a metal. A labelled diagram is given, but the anode and the cathode are specified on the diagram in LT (p. 180) and LLELA (p. 103) which illustrates the concept better to the students, while ELL further explains the conditions required for good quality plating (p. 163).

Effects of electrolysis in industries

LT provides the information regarding the expensive process of extraction of aluminium from bauxite, and highlights the importance of recycling aluminium which uses only 9% of the energy required in the electrolysis of bauxite (p. 177),

ELL also emphasised on saving about 91% of the energy (p.159) while LLELA explains that electrolysis in industries contributes to the problem of pollution and gives examples of pollutants (p. 103). All the three books describe the benefits and disadvantages of electrolysis, but LT provides more detailed information on the disadvantages (p. 181) which would be helpful for students to better understand the problem of environmental pollution.

Computer software on electrolysis

Besides using textbooks, schools in Malaysia offering Form Four chemistry are also provided with computer software supplied by the Curriculum Development Division. A review of the electrolysis concepts in the compact disc on electrolysis revealed very clear animations of a number of concepts on a molecular level. Some examples are the electrolysis of molten lead(II) bromide in lesson 50 of the compact disc (which will be referred to as CD Lesson 50), the electrolysis of dilute sulphuric acid using carbon electrodes (CD Lesson 52), the purification of copper metal using copper(II) sulphate solution (CD Lesson 57), and the electroplating of a copper coin with silver (CD Lesson 58). These computer animations should assist the students in better understanding of the concepts (Sanger & Greenbowe, 1997b; Yochum & Luoma, 1995).

Table 4.1 Summary of analysis of the three textbooks

Items	LLELA	ELL	LT
<i>Electrolytes and non-electrolytes</i>			
1. Is electrolyte defined clearly?	y	y	y
2. Is non-electrolyte defined clearly?	y	y	y
3. Is conduction of electricity in electrolytes explained?	y	y	y
<i>Electron flow in external circuit</i>			
1. Is the direction of flow of electrons explained?	n	y	y
<i>Electrolytic cell</i>			
1. Is the anode explained?	y	y	y
2. Is the cathode explained?	y	y	y
3. Is movement of anions explained?	y	y	y
4. Is the movement of cations explained?	y	y	y
5. Is the movement of electron in the electrolyte explained?	n	n	n

Active and inert electrodes

1. Is active electrode explained?	y	y	n
2. Is inert electrode explained?	y	y	y

Electrolysis of molten solutions

1. Is the identification of anions in the molten solution explained?	y	y	y
2. Is the identification of cations in the molten solution explained?	y	y	y
3. Is the migration of anions to the anode explained?	y	y	y
4. Is the migration of cations to the cathode explained?	y	y	y
5. Is half-equation written for the discharge of ion?	y	y	y

Electrolysis of aqueous solutions

1. Is the identification of anions in the aqueous solution explained?	y	y	y
2. Is the identification of cations in the aqueous solution explained?	y	y	y
3. Is the migration of anions to the anode explained?	y	y	y
4. Is the migration of cations to the cathode explained?	y	y	y
5. Is half-equation written for the discharge of ion?	y	y	y
6. Are the three factors for the selective discharge of ions explained?	y	y	y

Extraction of metals

1. Is the extraction of metals described with the help of a diagram?	y	y	y
2. Is the process of extraction of metals well explained?	y	y	y

Purification of metals

1. Are the substances to be used as the anode and the cathode well explained?	y	y	y
2. Is the direction of electron flow in the external circuit shown?	n	n	y
3. Is the difference in thickness of the electrodes shown in the diagram?	n	n	y

Electroplating of metals

1. Are the substances to be used as the anode, cathode and the electrolyte well defined?	y	y	y
2. Is the explanation with a labelled diagram?	y	y	y
3. Is the anode and cathode labelled on the diagram?	y	n	y
4. Are the conditions for good quality plating specified?	n	y	n

Effects of electrolysis in industries

1. Is the high cost of extraction of aluminium from bauxite explained with respect to energy used?	n	y	y
2. Are the benefits of the use of electrolysis in industries explained?	y	y	y
	(briefly)		
3. Are the disadvantages explained?	y	y	y
			(in more detail)

LLELA refers to *Chemistry Form 4*, ELL refers to *Focus Super Chemistry*, and LT refers to *Exploring Chemistry*

DISCUSSION

In the description of the process for purification of metals, LT provides adequate links such as the direction of flow of electron in the external circuit and the change in thickness of the cathode after electroplating. Students need explicit links like this to appreciate or understand electrolysis in a more meaningful manner.

From the results above, it can be seen that all the three textbooks provide adequate information for Form Four students, but textbooks ELL and LT cover all aspects in more details which is essential for deeper understanding of the concepts for the purpose of the Malaysian Certificate examination. With regard to extra information, these books give different emphasis on different aspects of electrolysis. So it is useful for teachers to look for information in all three books as resources; it cannot be pinpointed which textbook is the best. Teachers should decide on which textbooks to be used. Generally these textbooks contained very little information about circuits but adequately addressed oxidation and reduction; a similar finding to Garnett and Treagust (1992a, p. 123).

A review of the lessons on electrolysis in the compact disc supplied by the Malaysian Curriculum Department revealed clear animation of the electrolysis concepts as described above.

SUMMARY

This chapter has addressed Research Question 2 with the analyses of three textbooks commonly used in secondary schools in Kuching, Malaysia. All three textbooks are important sources of information for students on electrolysis, nevertheless, each book differs slightly in its emphasis on different aspects of electrolysis. It is more helpful to the students for textbooks to link important and relevant concepts.

The next chapter describes Study 1 and Study 2 in preparing the first version of the free response instrument.

CHAPTER FIVE

DEVELOPMENT OF THE FREE RESPONSE INSTRUMENT ON ELECTROLYSIS: STUDY 1 AND 2

INTRODUCTION

This chapter specifically addresses Research Questions 3 and 4. The concept map and propositional statements from Chapter 3 provided the framework for the development of a written test instrument to examine student understanding of the concepts of electrolysis. In Study 1, information collected from semi-structured student interviews in Interview One provided data on more difficult conceptual areas and this information was used in the development of 21 free response questions seeking free response answers from the students to prepare the content choice which made up the first tier of the two-tier multiple choice diagnostic instrument.

In study 2 the refined version of the free response instrument was then administered to 116 secondary students in School X, Kuching, Malaysia in April 2007 and the results were analysed to prepare the first version of the two-tier multiple choice diagnostic instrument which is described in the next chapter.

SUMMARY OF THE METHODOLOGY USED IN THE DEVELOPMENT OF THE FREE RESPONSE INSTRUMENT

The methodology used in the development of the free response instrument to examine secondary students' understanding of electrolysis is summarized to assist the reader in following the sections of this chapter. The methodology involved:

- Review of the literature to determine student knowledge in the area of electrolysis.
- Exploration of student understanding of electrolysis through semi-structured interviews in Interview One (October, 2006).
- Development of a 21 questions free response exercise to identify student alternative conceptions to be used in the content choice of the free response

instrument which is the first-tier of the two-tier multiple choice diagnostic instrument (November, 2006).

- Study 1 with the results from Interview One and the free response questions developed the first version of the free response instrument (January, 2007).
- Review of Study 1 resulted in the refinement of individual items to form a 21 item free response instrument (March, 2007).
- A matching of items in the instrument with relevant propositional statements, to identify the propositions examined by each item.
- Study 2 trialled the 21 item free response instrument on 116 students (April, 2007).
- Further improvements following the analysis of Study 2 resulted in the formation of a 21 item first version of the two-tier multiple-choice diagnostic instrument which is described in the next chapter.

STUDY 1: FIRST VERSION OF THE FREE RESPONSE INSTRUMENT

Prior to the development of the first version of the free response instrument, data on student understanding on electrolysis was collected from semi-structured student interviews in Interview One and the free response exercise on 21 questions that followed. The main aim was to identify possible alternative conceptions or conceptually difficult areas in the topic on electrolysis.

In developing the two-tier multiple-choice items, the format described by Treagust (1988, 1995) was followed, with four main aims in mind. First, items should be prepared to cover the known alternative conceptions and identified conceptually difficult areas. Second, items should be prepared to provide adequate coverage of the propositional statements. Third, items should be prepared to ensure adequate coverage of all regions of the concept map. Finally, each item should address a limited number of related propositional statements.

Study 1 aimed at producing items in the first tier of the two-tier multiple choice instrument, and this first tier is a multiple choice content question with two or three choices. Data from Interview One helped to identify the conceptually difficult areas

of electrolysis in particular and the 21 questions free response exercise that followed contributed to the content choice for the first-tier of the two-tier multiple-choice instrument. The second-tier of the two-tier multiple-choice instrument is developed from Study 2 carried out with 116 students in School X, Kuching, Malaysia in April, 2007.

Interview One

Interview One is a semi-structured interview conducted in October, 2006. Fifteen students from five Form Four classes T1, T2, T3, T4 and T5 of School Y, Kuching, Malaysia were individually interviewed for approximately ten minutes one month after completing the topic on electrolysis. These students were interviewed during their free time in the school resource room booked for the purpose. Teachers were asked to select students on the basis of their previous chemistry achievement in Semester 1, with one student from the top third of the class with high achievement, one from the middle third with moderate achievement, and one from the bottom third with low achievement. This follows a similar selection as in Garnett and Treagust (1992a). To get a fairer representation of data, the sample was selected from five different classes rather than the whole group from one particular class. A sample of 15 was considered as a reasonable size because this number would provide a range of student responses and a manageable number of interviews to conduct and analyse.

The semi-structured interviews were conducted in a one-to-one situation, began with the open-ended question:

“What did you find difficult to understand in the work you have done on electrolysis?”

Based on student responses to this question, more specific follow-up questions were asked. Examples of follow-up questions were:

“What part in particular did you find difficult to understand?”

“Why do you find it difficult to understand?”

“Can you give an example to help explain what you mean?”

Fifteen students took part in Interview One. Parts of the transcripts of six interviews with students of different achievement levels are given below. These interview transcripts identified the areas of conceptual difficulty for each student.

1. Student S04 (High achiever in class T1 who obtained 87% in semester 1 Form Four school chemistry examination)

I: What did you find difficult to understand in the work you have done on electrolysis?

S: Aa.... Electrolysis, yea, the flow of electron or the flow of electric current from the anode to cathode or cathode to anode, from the negative terminal to the positive terminal or positive terminal to the negative terminal, I find it very confusing.

I: Which part in particular did you find difficult to understand?

S: The types of ions discharged at each electrode, and it is different, depend on the factor,...factors, the concentration....so if this ion has higher concentration, then other ion discharged, although in higher concentration, normally lower ion is discharged than the one in higher concentration, so.....very confusing.

2. Student S03 (High achiever in class T4 who obtained 48% in semester 1 Form Four school chemistry examination)

I: Can you please tell me what did you find difficult to understand in the work you have done on electrolysis?

S: For me, I think the difficult part is when we have to know which solution is being used, and the products formed and how they form.

I: Can you give me one example to help explain that?

S: For example, how copper can become other....other products, and which type of solution is needed to use.

I: What part in particular did you find difficult to understand?

S: I find it difficult to understand the part where the ion moves from one bar to the other.

I: Hm...you mean the electrode?

S: Yes.

I: Why do you find it difficult?

S: Because I could not understand about electrolysis, and how it can help us in our life, which makes me confused.

3. Student S09 (Moderate achiever in class T3 who obtained 39% in semester 1 Form Four school chemistry examination)

I: Can you please tell me what did you find difficult to understand in the work you have done on electrolysis?

S: I find difficult to understand the positive and negative ions, movement of ions to electrodes, the discharge of ions, and the half equations.

I: Can you give me an example to explain what you mean?

S: When ions are discharged at the electrodes, they form atoms or molecules.

I: Which part in particular do you find it difficult to understand?

S: Action of the half equation, ahem...the anode and cathode gives the overall equation.

4. Student S05 (Moderate achiever in class T1 who obtained 45% in semester 1 Form Four school chemistry examination)

I: What did you find difficult to understand in the work you have done on electrolysis?

S: I think ah... the part on the purification of metal.

I: Can you give an example to help explain what do you mean?

S: (pause)....I don't know which metal... pure copper or impure copper should I place at the cathode or anode.

I: I see. Why do you find it difficult?

S: Because I have to do the whole process, like I have to know what ions are present,... like copper ion, what is the equation, and what is the product, then I have to know which part is the pure metal or impure metal.

5. Student S01 (Low achiever in class T5 who obtained 13% in semester 1 Form Four school chemistry examination)

I: What did you find difficult to understand in the work you have done on electrolysis?

S: I find that the product that are produced at the cathode and the anode.

- I: Can you give an example to help explain what you mean?
 S: For example, how the... position of ions affect the product produced.
- I: Do you mean the position of ions according to the electrochemical series? You find that difficult to remember?
 S: Hmm.
- I: Is there any part in particular you find difficult to understand?
 S: The chemical equation and the donating electrons.
- I: Do you mean when you write the half equations?
 S: Yes.
- I: Why do you find it difficult?
 S: For me, it is very hard to understand and very confusing.

6. Student S15 (Low achiever in class T2 who obtained 26% in semester 1 Form Four school chemistry examination)

- I: What did you find difficult to understand in the work you have done on electrolysis?
 S: Especially on extraction of metals, and electrolysis of aqueous solution.
- I: Can you give me an example to explain what you mean?
 S: Mostly the difficulty in the experiment and the chemical equation.
- I: Which part in particular did you find difficult to understand?
 S: Mostly on experiment, and the chemical equation on electrolysis.

Results of Interview One

Based on the interviews, students could offer one or two concepts or conceptual areas they had difficulty in understanding. On further questioning, students were unable to elaborate or give specific reasons for the nature of the difficulties that they encountered. For example, a student's reply to the questions:

“Electrolysis...I find it difficult to understand the part where the ion moves from one bar to the other...Because I could not understand about electrolysis, and how it can help us in our life, which makes me confused.”

This student could identify the conceptual area on the movement of ions to the electrodes but was unable to elaborate in more detail on the nature of the difficulty.

Through an analysis of all interview data in Interview One, the following concepts and conceptual areas were identified to be difficult for the students to understand.

- Flow of electrons
- Electrolysis of aqueous solutions
- Movement of ions to the electrodes
- Types of ions discharged at each electrode
- Types of electrodes
- Half equations
- Purification of metals
- Extraction of metals
- Position of ions in the electrochemical series

Development of Content Choice for the Free Response Instrument

Before the development of the free response instrument in Study 2, a free response exercise with 21 questions was prepared by using the data from Interview One, taking into consideration the concept map, the propositional statements and the syllabus. This set of questions was given to a group of 30 students of class T3 of School Y. Class T3 was chosen because this class consisted of students with high achievers, moderate achievers, and low achievers which will provide the responses required. The number of 30 students is considered adequate as Wiersma (2000) pointed out that a pilot run is done with a limited number of individuals, seldom more than 20. The free response exercise was conducted in the school resource room in October 2006, a month after Interview One. A set of the free response exercise with 21 questions can be found in Appendix C. Questions 4, 5 and 13 from the set of 21 questions are described below.

Question 4

In the electrolysis of molten magnesium oxide using carbon electrodes, at which electrode is magnesium produced?

Question 5

When a dilute solution of iron(II) sulphate is electrolysed using platinum electrodes, what happens to the light green colour of the solution?

Question 13

In order to purify an impure copper plate, which substance must be used as the cathode?

Data from Interview One helped to identify the conceptually difficult areas of electrolysis in particular and the 21 questions free response exercise that followed contributed to the content choice for the first tier of the two-tier multiple choice instrument. A summary of the alternative conceptions determined in Interview One and the free response exercise is shown in Table 5.1

Table 5.1 Summary of alternative conceptions determined in Study 1

Electrolysis Reactions	Question No.	Alternative Conceptions
Electrolyte and non-electrolyte	1	Tetrachloromethane is an electrolyte.
Electrolysis of molten lead(II) bromide using graphite electrodes	2	During electrolysis of molten lead(II) bromide using graphite electrodes, oxidation occurs at the cathode.
Manufacture of chlorine	3	In the manufacture of chlorine by electrolysis of concentrated aqueous sodium chloride using graphite electrodes, hydrogen gas is not produced.
Electrolysis of molten magnesium oxide using carbon electrodes	4	During electrolysis of a molten magnesium oxide using carbon electrodes, magnesium is produced at the anode.
Electrolysis of iron(II) sulphate solution using platinum electrodes	5	During electrolysis of iron(II) sulphate solution using inert electrodes, the colour of the solution becomes fainter. During electrolysis of iron(II) sulphate solution using inert electrodes, the colour of the solution remains the same.
Electrolysis of dilute sulphuric acid using inert electrodes	6	During electrolysis of dilute sulphuric acid using inert electrodes, the products are oxygen at the cathode and hydrogen at the anode. During electrolysis of dilute sulphuric acid using inert electrodes, sulphur dioxide is produced at the anode and oxygen is produced at the cathode.
Electrolysis of aqueous zinc nitrate using graphite electrodes	7	When aqueous zinc nitrate is electrolysed using graphite electrodes, hydrogen gas is given off at the cathode. When aqueous zinc nitrate is electrolysed using graphite electrodes, zinc is deposited at the cathode.
Electrolysis of dilute sulphuric acid using inert electrodes	8	During electrolysis of dilute sulphuric acid using inert electrodes, the concentration of the solution decreases. During electrolysis of dilute sulphuric acid using inert electrodes, the concentration of the solution remains unchanged.

Electrolysis Reactions	Question No.	Alternative Conceptions
Electrolysis of copper(II) sulphate solution using platinum electrodes	9	During electrolysis of copper (II) sulphate solution using platinum electrodes, the colour of the electrolyte increases in intensity. During electrolysis of copper (II) sulphate solution using platinum electrodes, the colour of the electrolyte remains unchanged.
Electrolysis of concentrated aqueous solution of copper(II) chloride using inert graphite electrodes	10	During electrolysis of concentrated aqueous solution of copper(II) chloride using graphite electrodes, copper(II) ions are oxidised. During electrolysis of concentrated aqueous solution of copper(II) chloride using graphite electrodes, chloride ions are reduced.
Electroplating a metal spoon with silver	11	In electroplating an iron spoon with silver, a carbon rod should be used as the cathode. In electroplating an iron spoon with silver, a silver strip should be used as the cathode.
Electrolysis of brass (alloy of zinc and copper) as the anode	12	In the electrolysis of brass as the anode and platinum as the cathode, copper dissolves at the anode and hydrogen gas is given off at the cathode. In the electrolysis of brass as the anode and platinum as the cathode, copper dissolves at the anode and oxygen gas is given off at the cathode.
Purifying an impure copper plate	13	In purifying an impure copper plate, an impure copper plate should be used as the cathode. In purifying an impure copper plate, a carbon rod should be used as the cathode.
Electrolysis of molten lead(II) chloride and aqueous silver nitrate	14	In the electrolysis of molten lead(II) chloride and aqueous silver nitrate, the anodes W and Y will increase in mass.
Extraction of aluminium metal from aluminium oxide	15	In the extraction of aluminium by the electrolysis of molten aluminium oxide using graphite electrodes, the cathode has to be replaced periodically.
Effect on the environment by the use of electrolysis in industry	16	The use of electrolysis in industry does not cause pollution of the environment.
Electroplating in the motor industry	17	In the motor industry, electroplated nickel or chromium is not widely used as the coating system.
Electroplating on cutlery items	18	Cutlery items are often electroplated with silver alone, not with silver and nickel.
Electroplating on wrist watches	19	Gold-plated wrist watches are more expensive than gold watches.
Electrodes: Anode and cathode	20	The anode is the electrode that is connected to the negative terminal of the battery.
Movement of electrons in the electrolyte	21	The movement of electrons is from the negative terminal to the positive terminal of the battery in the external circuit. The movement of electrons is from the anode to the cathode in the electrolyte.

In Study 1, the first version of the free response instrument is prepared. Twenty one items of the first version of the free response instrument were prepared from the 21

questions in the free response exercise. Item 4 regarding the electrolysis of molten magnesium oxide was prepared from question 4; item 5 regarding the electrolysis of iron(II) sulphate solution was prepared from question 5; and item 13 regarding the substance to be used as the cathode in purifying an impure copper plate was prepared from question 13 are described below. All 21 items are shown in Appendix F1.

Item 4 was prepared to test a known student difficulty related to determining the product of electrolysis produced at the electrode. This difficulty was previously identified in Interview One as being difficult for students to understand. In the 21 questions free response exercise, the answers given by the students for question 4 were 'at the cathode' and 'at the anode'. These two answers were then chosen to be the two content choices for item 4: (1) At the cathode, (2) At the anode.

Similarly item 5 was prepared to test a known student difficulty related to the ions present in the solution. Students wrote that the colour of the solution 'becomes darker', 'becomes fainter', and 'remains the same'. These answers were then selected to be the content choices for item 5: The colour of the solution (1) becomes darker, (2) becomes fainter, and (3) remains the same.

Item 13 was prepared to test a known student difficulty related to determining the substance to be used as the cathode in electroplating an impure copper plate. Students wrote answers such as 'an impure copper plate' and 'a pure copper plate', for question 13 in the free response exercise. These answers were then included as the content choices for item 13: (1) An impure copper plate, (2) A pure copper plate.

Similarly, all the other items were prepared in the process described above. Other items which were based on conceptually difficult areas are:

Items 2, 3, 6 - regarding the products of electrolysis.

Items 5, 8, 9 –regarding the electrolyte and inert electrodes.

Items 11– regarding electroplating.

Items 13– regarding purifying an impure copper plate

Item 14 – regarding electrolysis of molten and aqueous compounds

Item 15 – regarding extraction of metal.

Item 16 – impact on the environment.

Items 17, 18, 19 – use of electroplating in industry.

Item 20 – identifying the anode and cathode.

Item 21 – identifying the direction of flow of electrons.

Matching of the Propositions with Individual Items

A matching of the items with the corresponding propositional statements was completed by the author. Through this process it was possible to identify the main propositions measured by each item of the 21 item instrument. To answer a particular item, it would require an understanding of the corresponding propositional statements related to each item. Details of this matching process is given in Table 5.2.

Table 5.2 Matching of the propositional statements to each item of the 21 item in the first version of the free response instrument

Item Number	Propositional Statements
1	1, 2, 3
2	13, 15, 16, 18, 19
3	22, 23, 24
4	13, 15, 16, 17
5	21, 22, 23, 24, 25
6	22, 23, 24, 25, 26
7	23, 24, 25
8	25, 26, 27
9	28, 29, 30, 32
10	7, 19, 23, 24, 25
11	12, 37, 39
12	5, 15, 16
13	12, 22, 23, 24, 36
14	1, 7, 8, 14, 15, 16
15	10, 15, 16, 35
16	34, 41
17	37, 38
18	37, 38
19	37, 38
20	7, 10, 13, 15, 16
21	5, 7, 14

STUDY 2: SECOND VERSION OF THE FREE RESPONSE INSTRUMENT

Development of the second version of the free response instrument

The 21-item second version of the free response instrument (Appendix F2) was developed from the first version of the free response instrument (Appendix F1). The questions were reviewed, and modifications were made on the first version of the instrument. Table 5.3 describes how the second version of the free response instrument was developed from the first version.

Table 5.3 Development of the second version of the free response instrument

Item No. in Second Version	Item No. in First Version	Changes Made
Item 1	Item 1	No changes were made.
Item 2	Item 2	No changes were made.
Item 3	Item 3	'Concentrated sodium chloride' was changed to 'Concentrated aqueous sodium chloride'.
Item 4	Item 4	No changes were made.
Item 5	Item 5	'When a dilute solution of iron(II) sulphate' was changed to 'When aqueous iron(II) sulphate'
Item 6	Item 6	No changes were made.
Item 7	Item 7	'Initially' in the stem was deleted.
Item 8	Item 8	No changes were made.
Item 9	Item 9	'Copper(II) sulphate solution' was changed to 'Aqueous copper(II) sulphate'.
Item 10	Item 10	The labelling of electrode P and Q is changed to electrode X and Y respectively in order not to link the 'P' with 'positive'.
Item 11	Item 11	No changes were made.
Item 12	Item 12	No changes were made.
Item 13	Item 13	Content choice (3) A carbon rod is added.
Item 14	Item 14	'Which pair of electrodes' was changed to 'Which electrode', and content choices (1) and (2) were changed to (1) W, (2) X, (3) Y, (4) Z.
Item 15	Item 15	No changes were made.
Item 16	Item 16	No changes were made.
Item 17	Item 17	No changes were made.
Item 18	Item 18	No changes were made.
Item 19	Item 19	No changes were made.
Item 20	Item 20	No changes were made.
Item 21	Item 21	No changes were made.

Table 5.4 Table of specifications for the second version of the free response instrument

Item No.	Concepts Tested	Propositional Knowledge Statements
1	Electrolyte and non-electrolyte	1, 2, 3
2	Electrolysis of molten lead(II) bromide	13, 15, 16, 18, 19
3	Manufacture of chlorine	22, 23, 24
4	Electrolysis of molten magnesium oxide	13, 15, 16, 17
5	Electrolysis of aqueous iron(II) sulphate using platinum electrodes	21, 22, 23, 24, 25
6	Products of electrolysis of dilute sulphuric acid using inert electrodes	22, 23, 24, 25, 26
7	Electrolysis of aqueous zinc nitrate using graphite electrodes	23, 24, 25
8	Change to the concentration of electrolyte during electrolysis of dilute sulphuric acid using inert electrodes	25, 26, 27
9	Electrolysis of aqueous copper(II) sulphate using platinum electrodes	28, 29, 30, 32
10	Electrolysis of concentrated aqueous solution of copper(II) chloride using graphite electrodes	7, 19, 23, 24, 25
11	Electroplating an iron spoon	12, 37, 39
12	Electrolysis of dilute sulphuric acid using brass as the anode	15, 16, 22, 23, 24, 25
13	Purifying an impure copper plate	12, 22, 23, 24, 36
14	Electrolysis of molten lead(II) chloride and aqueous silver nitrate	1, 7, 8, 14, 15, 16
15	Electrolysis of molten aluminium oxide using graphite electrodes	10, 15, 16, 35
16	Effect on the environment by the use of electrolysis in industry	34, 41
17	Electroplating in the motor industry	37, 38
18	Electroplating on cutlery items	37, 38
19	Electroplating on gold watches	37, 38
20	Electrodes: Anode and cathode	7, 10, 13, 15, 16
21	Direction of electron flow in a circuit	5, 7, 14

The specifications for each question in the second version of the free response instrument are given in Table 5.4. Two chemistry lecturers from two different teachers training colleges in Kuching, Mrs. J and Ms K, and three secondary school

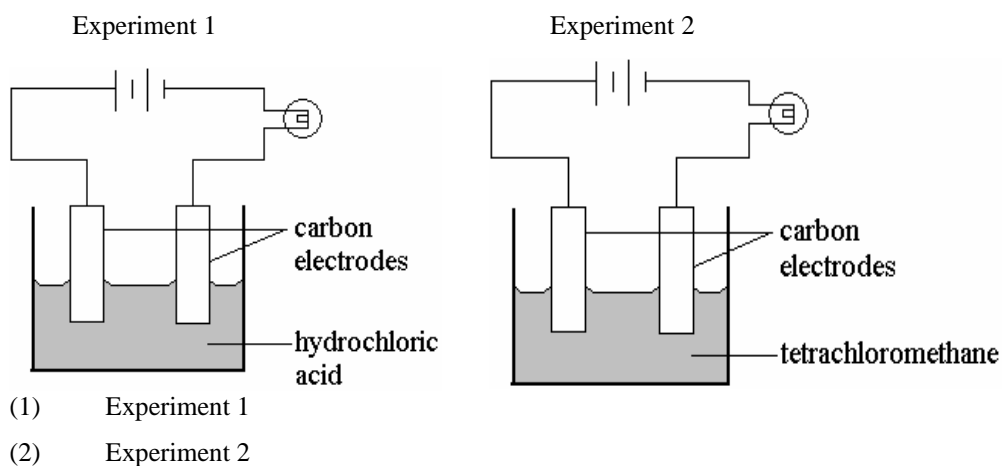
chemistry teachers in Kuching, Mrs. F, Mrs. G and Mrs. H, reviewed the free response instrument before it was administered to the students.

The results from the administration of the free response instrument

The administration of the second version of the free response instrument was carried out in the last week of April 2007 with three classes of M1, M2 and M3 of School X, Kuching, Malaysia. This test was given to the students as a revision of their Form Four topic on electrolysis. The students have been informed by their teachers to do revision on this topic. After the students did the test, the answers were marked by the researcher and feedback was given to the teachers after one week of the test.

The Form Five science students were chosen because the topic on electrolysis was taught in Form Four in August 2006, as such the Form Four science students in 2007 had not been taught this topic. The test was also given as a revision as they prepare for their coming Semester 1 examination in May 2007. The results of the test are discussed in the following sections.

1. In which of the following two experiments would you expect the bulb to light up?



Answer	M1	M2	M3	Total	Percentage
*1	37	37	41	115	99.1
2	1	0	0	1	0.9
Total	38	37	41	116	100.0

Out of the 115 (37 + 37 + 41) students who chose answer 1, 80 wrote that hydrochloric acid consists of free moving ions; 25 wrote that acid can conduct

electricity, eight did not give any reason; two wrote that hydrochloric acid reacted with carbon electrodes to complete the circuit. *Students are not clear about the role of carbon electrodes in electrolysis.*

2. During electrolysis of molten lead(II) bromide using graphite electrodes, reddish fumes of bromine gas and molten lead are produced. At which electrode does oxidation occur?

- (1) At the cathode
(2) At the anode

Answer	M1	M2	M3	Total	Percentage
1	14	9	2	25	21.6
*2	22	24	37	83	71.6
0	2	4	2	8	6.9
Total	38	37	41	116	100.0

Out of the 25 (14 + 9 + 2) students who chose answer 1, eight wrote that lead ions being positive move to the cathode; three wrote that the cathode being negatively charged produces oxygen, *showing that students are not clear about the product produced at the cathode*; 14 others did not give any reason. Out of the 83 (22 + 24 + 37) students who chose answer 2, 43 wrote that oxidation being a loss of electrons, bromide ions lose electrons to form bromine atoms at the anode; ten wrote that oxygen is attracted to the anode, *this is probably due to rote learning of connecting oxygen as a product with the anode*. Eight wrote that the anode is the positive terminal which attracts anions; two wrote that the anode contains positive charges; 20 did not give any reason.

3. In the manufacture of chlorine by electrolysis of concentrated aqueous sodium chloride using graphite electrodes, hydrogen gas is also produced.

- (1) True
(2) False

Answer	M1	M2	M3	Total	Percentage
*1	24	18	36	78	67.2
2	11	17	4	32	27.6
0	3	2	1	6	5.2
Total	38	37	41	116	100.0

Out of the 78 (24 + 18 + 36) students who chose answer 1, 40 wrote that hydrogen ions are selectively discharged over sodium ions; three wrote that hydrogen ions are preferably discharged over hydroxide ions, *showing a poor understanding of the*

electrochemical series for the discharge of ions; four wrote that hydrogen gas is produced at the cathode; two wrote that both hydrogen and chlorine gas are produced; 29 did not give any reason.

4. In the electrolysis of molten magnesium oxide using carbon electrodes, at which electrode is magnesium produced?

- (1) At the cathode
(2) At the anode

Answer	M1	M2	M3	Total	Percentage
*1	25	33	38	96	82.8
2	13	4	2	19	16.4
0	0	0	1	1	0.9
Total	38	37	41	116	100.0

Out of the 96 (25 + 33 + 38) students who chose answer 1, 55 wrote that magnesium ion is a cation, so it is attracted to the cathode which is negatively charged; 20 wrote magnesium ions receive electrons that are released from the anode to produce magnesium metal at the cathode; four wrote that magnesium has negative charge, so it is attracted to the negative terminal, *this shows that some students are not sure of the charge of magnesium ion, whether magnesium ion is a cation or an anion*; 17 did not give any reason.

5. When aqueous iron(II) sulphate is electrolysed using platinum electrodes, what happens to the light green colour of the solution?

The colour of the solution

- (1) becomes darker.
(2) becomes fainter.
(3) remains the same.

Answer	M1	M2	M3	Total	Percentage
*1	6	5	17	28	24.1
2	17	24	18	59	50.9
3	11	5	5	21	18.1
0	4	3	1	8	6.9
Total	38	37	41	116	100.0

Out of the 28 (6 + 5 + 17) students who chose answer 1, 15 wrote that hydrogen ions are preferably discharged over iron(II) ions, so the concentration of the iron(II) ions increases; three wrote that iron corrodes and dissolves into the solution, *showing lack of understanding of ions in the electrolysis of an aqueous solution*; ten did not give

any reason. Out of the 59 (17 + 24 + 18) students who chose answer 2, 24 wrote that the concentration of iron(II) ions decreases as it gets deposited at the cathode, therefore the green colour becomes fainter. In choosing answer 2, *students tend to remember electrolysis of copper(II) sulphate solution where the blue colour of the solution fades as electrolysis proceeds. This error could also arise due to the confusion between inert and active electrodes.* Eleven students wrote that iron(II) ions are displaced, *showing poor understanding of ions in aqueous solution during electrolysis*; two wrote that iron(II) ions are oxidised to iron(III) ions; 22 did not give any reason. Out of the 21 (11 + 5 + 5) students who chose answer 3, eight wrote that hydrogen and hydroxide ions are discharged, but iron(II) ions are not discharged at the cathode; three wrote there is no change in ions; five wrote hydrogen is released at the cathode, *showing partial understanding of the products produced at the electrodes*; three wrote hydrogen ion is selectively discharged over iron(II) ion; two gave no reason.

6. What are the products of electrolysis of dilute sulphuric acid using inert electrodes?

	<i>Product at anode</i>	<i>Product at cathode</i>
(1)	Hydrogen	Oxygen
(2)	Water vapour	Sulphur dioxide
(3)	Oxygen	Hydrogen
(4)	Sulphur dioxide	Oxygen

Answer	M1	M2	M3	Total	Percentage
1	4	5	6	15	12.9
2	6	5	0	11	9.5
*3	14	24	32	70	60.3
4	10	1	1	12	10.3
0	4	2	2	8	6.9
Total	38	37	41	116	100.0

Out of the 15 (4 + 5 + 6) students who chose answer 1, three wrote that sulphur dioxide is absorbed at the cathode; three wrote that sulphate and hydrogen ions are discharged, *showing poor understanding of the ions discharged*; nine did not give any reason. Out of the 11 (6 + 5 + 0) students who chose answer 2, three wrote that sulphate and hydroxide ions are discharged, *displaying lack of understanding in the ions discharged*; eight did not give any reason. Out of the 70 (14 + 24 + 32) students who chose answer 3, 43 wrote that hydrogen ions move to the cathode producing hydrogen while hydroxide ions move to the anode producing oxygen; two wrote that

hydrogen ions are cations, oxygen ions are anions, *suggesting that oxygen is released from the selective discharge of oxygen ions*; 25 did not give any reason. Three out of the 12 (10 + 1 + 1) students who chose answer 4, three wrote that sulphuric acid releases sulphur dioxide; another three wrote that sulphur dioxide is a cation, so it gets deposited at the anode, *showing poor understanding of the ions present in an aqueous solution* ; six others did not give any reason.

7. What will happen when aqueous zinc nitrate is electrolysed using graphite electrodes?

- (1) The concentration of the zinc nitrate solution increases
- (2) Effervescence occurs only at the cathode
- (3) The mass of the anode decreases
- (4) The mass of the cathode increases

Answer	M1	M2	M3	Total	Percentage
*1	6	5	15	26	22.4
2	11	17	16	44	37.9
3	5	4	2	11	9.5
4	8	7	2	17	14.7
0	8	4	6	18	15.5
Total	38	37	41	116	100.0

Fifteen out of the 26 (6 + 5 + 15) students who chose answer 1 stated that hydrogen and hydroxide ions are selectively discharged over zinc and nitrate ions, thus the concentration of the solution increases; one wrote that reaction occurs between zinc ions and the graphite electrodes, *showing poor understanding of graphite as an inert electrode*; ten did not give any reason. Sixteen out of the 44 (11 + 17 + 16) students who chose answer 2 thought that only hydrogen gas is released at the cathode, thus effervescence occurs at the cathode, *showing poor understanding of the selective discharge of ions at the electrodes*; two wrote nitrogen gas is released; three wrote that zinc is displaced, *suggesting confusion with the displacement of ions learnt in previous lessons*; 23 others did not give any reason. Three out of the 11 (5 + 4 + 2) students who chose answer 3 wrote that graphite dissolves in the solution, *showing the alternative conception that graphite electrodes are active electrodes*; eight did not give any reason. Eight out of the 17 (8 + 7 + 2) students who chose answer 4 stated that zinc is deposited at the cathode, *showing poor understanding of the selective discharge of ions*; two wrote that reaction occurs between zinc ions and the graphite electrodes; seven did not give any reason. Eighteen (8 + 4 + 6) of the students did not give any answer.

8. When dilute sulphuric acid is electrolysed using inert electrodes, what happens to the concentration of the electrolyte?

The concentration of the electrolyte

- (1) remains unchanged
- (2) increases
- (3) decreases

Answer	M1	M2	M3	Total	Percentage
1	10	10	8	28	24.1
*2	8	10	15	33	28.4
3	16	15	15	46	39.7
0	4	2	3	9	7.8
Total	38	37	41	116	100.0

Seven out of the 28 (10 + 10 + 8) students who chose answer 1 wrote that the same number of hydrogen ions and hydroxide ions are released at the same time, so the concentration remains the same. Another five wrote that the electrolytes are inert *showing poor understanding of dilute sulphuric acid as an electrolyte*; 16 did not give any reason. Fourteen out of 33 (8 + 10 + 15) who chose answer 2 wrote that hydroxide ions are discharged at the anode and hydrogen ions are discharged at the cathode, resulting in the volume of water to decrease, thus the concentration of the electrolyte increases; 19 did not give any reason. Sixteen out of 46 (16 + 15 + 15) who chose answer 3 wrote that the hydrogen ions from the acid are electrolysed to form hydrogen gas, thus concentration of the acid decreases; three wrote that hydrogen and oxygen ions are selectively discharged, *displaying the alternative conception that oxygen is released from oxygen ions*; 27 did not give any reason.

9. Aqueous copper(II) sulphate is electrolysed using platinum electrodes, and a reddish-brown deposit is produced at the cathode. What happens to the blue colour of the electrolyte?

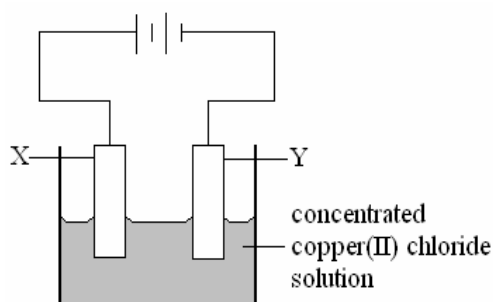
The colour of the electrolyte

- (1) increases in intensity
- (2) decreases in intensity
- (3) remains unchanged

Answer	M1	M2	M3	Total	Percentage
1	6	6	0	12	10.3
*2	22	25	38	85	73.3
3	3	4	0	7	6.0
0	7	2	3	12	10.3
Total	38	37	41	116	100.0

Eleven out of the 12 (6 + 6 + 0) students who chose answer 1 wrote that the copper(II) ions dissolve in the electrolyte, *showing lack of understanding of aqueous solutions in electrolysis*. Out of the 85 (22 + 25 + 38) students who chose answer 2, 34 wrote that the concentration of copper(II) ions decrease; 20 stated that copper(II) ions are discharged and deposited at the cathode, thus decreasing the intensity of the electrolyte while 16 stated that the copper(II) ions are displaced by platinum, *displaying the alternative conception of the role of inert electrode*; 15 did not give any reason. Six out of the seven (3 + 4 + 0) students who chose answer 3 wrote that platinum electrodes are inert, *showing lack of understanding of inert electrodes*. Twelve (7 + 2 + 3) of the students did not give any answer.

10. The diagram below shows an electrolytic cell in which an electric current passes through a concentrated aqueous solution of copper(II) chloride using inert graphite electrodes.



Which of the following occurs at electrode X?

- (1) Copper(II) ions are reduced
- (2) Copper(II) ions are oxidised
- (3) Chloride ions are oxidised
- (4) Chloride ions are reduced

Answer	M1	M2	M3	Total	Percentage
1	8	8	1	17	14.7
2	10	9	4	23	19.8
*3	12	14	26	52	44.8
4	2	2	5	9	7.8
0	6	4	5	15	12.9
Total	38	37	41	116	100.0

Five out of the 17 (8 + 8 + 1) students who chose answer 1 wrote that copper ions are attracted to the anode X, *showing the alternative conception that cations (positively-charged ions) move to the anode as reported in Garnett and Treagust (1992b)*; 12 did not give any reason. Four out of the 23 (10 + 9 + 4) students who chose answer 2

stated that copper ions are attracted to the anode X; three wrote that chloride ions are discharged at the cathode *displaying the alternative conception that anions move to the anode* (Garnett & Treagust, 1992b; Sanger & Greenbowe, 1997a); 16 did not give any reason. Thirty one out of the 52 (12 + 14 + 26) students who chose answer 3 wrote that chloride ions are being discharged due to higher concentration; four wrote that chloride ions are discharged at the cathode; 17 others did not give any reason.

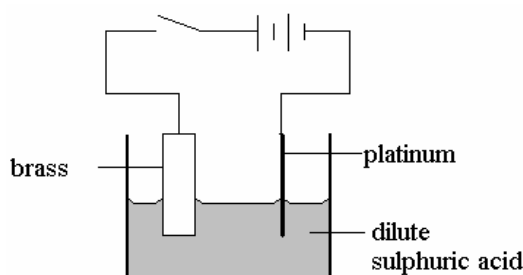
11. In order to electroplate a metal spoon with silver, which of the following should be used as the cathode?

- (1) A copper strip
- (2) The spoon
- (3) A carbon rod
- (4) A silver strip

Answer	M1	M2	M3	Total	Percentage
1	4	1	0	5	4.3
*2	20	31	38	89	76.7
3	3	0	0	3	2.6
4	8	4	1	13	11.2
0	3	1	2	6	5.2
Total	38	37	41	116	100.0

Forty five out of the 89 (20 + 31 + 38) students who chose answer 2 wrote that silver ions from the solution will receive electrons to form silver which will coat the spoon; 11 wrote that silver metal is transferred from the anode to the spoon and deposited, *showing lack of understanding of the movement of ions in electroplating*; five wrote that the spoon should be the cathode for electroplating to occur; 28 did not give any reason. Five out of the 13 (8 + 4 + 1) students who chose answer 4 regarded the silver strip to be the cathode giving the reason that only silver ions can electroplate the spoon. *They may be confused with the idea that the silver ions will come from the silver strip which is the cathode.* Eight others did not give any reason.

12. Brass is an alloy of copper (60%) and zinc (40%). The diagram shows the apparatus that is used to carry out electrolysis using brass as the anode.



What happens at the electrodes when the circuit is first closed?

	Anode	Cathode
(1)	Zinc and copper dissolve	Copper is deposited
(2)	Zinc dissolves	Hydrogen gas is liberated
(3)	Copper dissolves	Oxygen gas is liberated
(4)	Copper dissolves	Hydrogen gas is liberated

Answer	M1	M2	M3	Total	Percentage
1	10	11	7	28	24.1
*2	6	7	15	28	24.1
3	3	5	5	13	11.2
4	14	9	8	31	26.7
0	5	5	6	16	13.8
Total	38	37	41	116	100.0

Seven out of the 28 (10 + 11 + 7) students who chose answer 1 wrote that copper is lower than zinc, and hydrogen gas is liberated; five wrote that zinc and copper are more electropositive than hydrogen ion, *displaying lack of understanding in the selective discharge of ions in the electrochemical series*; two wrote that copper ions from the anode are deposited as copper at the cathode; 14 others did not give any reason. Out of the 28 (6 + 7 + 15) students who chose answer 2, eight wrote that zinc is more electropositive, and hydrogen gas is produced at the cathode; 20 others did not give any reason. Three out of the 13 (3 + 5 + 5) students who chose answer 3 wrote that copper is lower than zinc, so copper ions from the anode is deposited as copper at the cathode; nine others did not give any reason. Out of the 31 (14 + 9 + 8) students who chose answer 4, five wrote that copper is lower than zinc, and hydrogen gas is liberated; 25 others did not give any reason. *(This item was omitted because it is testing too many concepts.)*

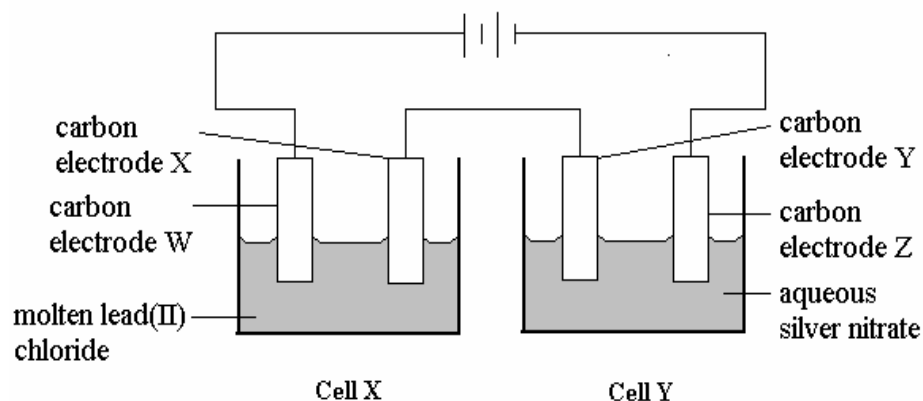
13. In order to purify an impure copper plate, which of the following must be used as the cathode?

- (1) An impure copper plate
- (2) A pure copper plate
- (3) A carbon rod

Answer	M1	M2	M3	Total	Percentage
1	10	12	5	27	23.3
*2	13	20	32	65	56.0
3	12	2	2	16	13.8
0	3	3	2	8	6.9
Total	38	37	41	116	100.0

Twelve out of the 27 (10 + 12 + 5) students who chose answer 1 wrote that impure copper plate must be the cathode, *showing lack of understanding of electrodes in the purification of metal*; 14 others did not give any reason. Out of the 65 (13 + 20 + 32) students who chose answer 2, 24 wrote that copper ions from the solution will receive electrons to form pure copper at the cathode; 14 wrote that this is to purify an impure copper plate; five wrote that the copper ions at the cathode will be attracted to the impure copper plate at the anode. *These students are displaying the misconception that copper ions which are cations move to the anode (Garnett & Treagust, 1992b)*. Another two wrote that pure copper is deposited at anode; 20 other students did not give any reason. Out of the 16 (12 + 2 + 2) students who chose answer 3, five wrote that the impurities on the copper plate will be dissolved; three wrote that the carbon rod is suitable, *displaying poor understanding of purification of metal*; eight others did not give any reason.

14. The diagram below shows the set-up of apparatus to investigate the electrolysis of molten lead(II) chloride and aqueous silver nitrate.



Which electrode will increase in mass?

- (1) W (3) Y
(2) X (4) Z

Answer	M1	M2	M3	Total	Percentage
1	5	5	3	13	11.2
2	7	12	3	22	19.0
3	7	9	0	16	13.8
*4	16	6	31	53	45.7
0	3	5	4	12	10.3
Total	38	37	41	116	100.0

Out of the 13 (5 + 5 + 3) students who chose answer 1, two wrote that lead is a heavy metal which has high surface tension; eleven others did not give any reason. Out of the 22 (7 + 12 + 3) who chose answer 2, four wrote that molten lead(II) chloride will help Y to increase in mass, another four wrote that lead ions will be deposited at X, which is the cathode in Cell X, *showing lack of knowledge in the high surface tension of lead*; 14 others did not give any reason. Out of the 16 (7 + 9 + 0) who chose answer 3, two wrote that silver will be collected the electrode Y; 14 others did not give any reason. Fourteen out of the 53 (16 + 6 + 31) students who chose answer 4 wrote that Z acts as the cathode, so silver will be deposited; five wrote that silver is lower than hydrogen in the electrochemical series; 34 others did not give any reason. This item was omitted because it was testing too many concepts. *Z acts as cathode, and silver is deposited. Lead is a heavy metal which has high surface tension, so it will not get deposited at X, instead it will sink to the bottom of the cell X.*

15. In the extraction of aluminium by the electrolysis of molten aluminium oxide using graphite electrodes, which of the electrodes has to be replaced periodically?

- (1) Anode
(2) Cathode

Answer	M1	M2	M3	Total	Percentage
*1	10	20	25	55	47.4
2	23	13	12	48	41.4
0	5	4	4	13	11.2
Total	38	37	41	116	100.0

Out of the 55 (10 + 20 + 25) students who chose answer 1, 16 wrote that oxygen reacts with carbon to form carbon dioxide, hence the carbon electrode will erode over time; eight wrote that the mass of anode will decrease *as the anode dissolves to give aluminium ions to be deposited at the cathode*; two wrote to avoid overheating that will disrupt the extraction; 29 others did not give any reason. Eight out of the 48 (23 + 13 + 12) students who chose answer 2 wrote that aluminium deposits at the cathode; two wrote that the anode becomes smaller as the ions move from the anode to the cathode; two wrote that oxidation occurs at the cathode, *showing the misconception of where oxidation occurs in electrolysis*; 36 others did not give any reason.

16. The use of electrolysis in industry causes pollution as a result of

- (1) the release of poisonous gases like chlorine into the environment.
(2) chemical wastes, such as cadmium ion and nickel ion, from the electrolytic industries released into the water sources.
(3) proper treatment of the chemical wastes before they are released into the environment.

Answer	M1	M2	M3	Total	Percentage
1	14	9	10	33	28.5
*2	19	23	29	71	61.2
3	1	1	0	2	1.7
0	4	4	2	10	8.6
Total	38	37	41	116	100.0

Out of the 33 (14 + 9 + 10) students who chose answer 1, seven wrote that the electrolytic process produces poisonous gases; six wrote that chemical waste is toxic; two wrote that chloride ions are selectively discharged, *showing lack of understanding of the effects of electrolysis in industry*; 18 others did not give any

reason. Out of the 71 (19 + 23 + 29) students who chose answer 2, 17 wrote that chemical waste contaminate the water and aquatic organisms will die; five wrote that pollutants such as poisonous gases are produced; 49 did not give any reason.

Items 17 – 19 are three examples in which electrolysis is used in industry for electroplating.

17. In the motor industry, electroplated nickel or chromium is widely used as the coating system.

(1) True

(2) False

Answer	M1	M2	M3	Total	Percentage
*1	30	25	33	88	75.9
2	4	9	3	16	13.8
0	4	3	5	12	10.3
Total	38	37	41	116	100.0

Out of the 88 (30 + 25 + 33) students who chose answer 1, 19 wrote that the reason is to prevent rusting; eight wrote that it is durable and last longer; five wrote that it is cheap and affordable, *showing a lack of understanding of electroplating in industry*; four wrote that nickel and chromium have high boiling and melting point *which is a correct property of the metals but does not explain the reason for use in the electroplating industry*; 52 others did not give any reason. Out of the 16 (4 + 9 + 3) students who chose answer 2, five wrote that it is not suitable for electroplating as the metals are not reactive chemically; eleven others did not give any reason.

18. Cutlery items are often electroplated with silver alone, not with silver and nickel.

(1) True

(2) False

Answer	M1	M2	M3	Total	Percentage
1	21	19	7	47	40.5
*2	11	16	31	58	50.0
0	6	2	3	11	9.5
Total	38	37	41	116	100.0

Out of the 47 (21 + 19 + 7) students who chose answer 1, five wrote that nickel is dangerous to human body; four wrote that cutlery items are often plated with pure silver, *this could be due to students' observation and understanding based on what they have learnt in other areas regarding ornaments plated with pure metal*; three

wrote that it is to make the cutlery rust proof; 35 others did not give any reason. Twelve out of the 58 (11 + 16 + 31) students who chose answer 2 wrote that silver is too expensive; five wrote that cutlery items are often electroplated with other metals such as aluminium, *this is perhaps related to everyday experience as spoons and pots are often plated with aluminium*; four wrote to make it rust proof; three wrote nickel may react with food; 34 others did not give any reason.

19. Gold-plated wrist watches are more expensive than gold watches.

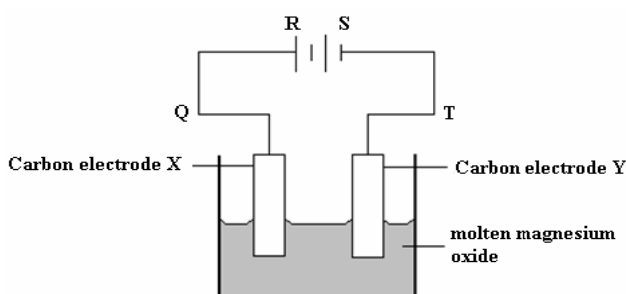
- (1) True
- (2) False

Answer	M1	M2	M3	Total	Percentage
1	17	5	12	34	29.3
*2	19	30	26	75	64.7
0	2	2	3	7	6.0
Total	38	37	41	116	100.0

Out of the 34 (17 + 5 + 12) students who chose answer 1, seven wrote that the process of electroplating is troublesome and complicated; three wrote that gold-plated is made up of gold metal, *showing that they do not understand the meaning of gold-plated*; two wrote that gold-plated has better quality, *again showing lack of understanding in electroplating*; 22 others did not give any reason. Out of the 75 (19 + 30 + 26) students who chose answer 2, 32 wrote that gold-plated is a thin layer of gold covering the object, so it is less expensive; eight wrote that only a part is made up of gold; five wrote that gold watches use pure gold; 30 others did not give any reason.

Items 20 and 21 refer to the diagram below.

The diagram shows the electrolysis of molten magnesium oxide.



20. Which electrode is the anode?

- (1) Electrode X
- (2) Electrode Y

Answer	M1	M2	M3	Total	Percentage
*1	28	29	40	97	83.6
2	10	8	1	19	16.4
Total	38	37	41	116	100.0

Ninety out of the 97 ($28 + 29 + 40$) students who chose answer 1 wrote that X is connected to the positive terminal of the battery; two did not give any reason. Sixteen out of the 19 ($10 + 8 + 1$) students who chose answer 2 wrote that Y which is connected to the negative terminal of the battery is the anode, *showing that the students are not definite of the terminology anode, probably confused with the anode in galvanic cells. These students also show an alternative conception similarly reported in Garnett and Treagust (1992b) that the polarity of the applied voltage has no effect on the site of the anode and cathode.* Three others did not give any reason.

21. The direction of the movement of electrons is from

- (1) R to Q in the external circuit
- (2) S to T in the external circuit
- (3) electrode X to electrode Y in the electrolyte
- (4) electrode Y to electrode X in the electrolyte

Answer	M1	M2	M3	Total	Percentage
1	4	3	0	7	6.0
*2	10	9	37	56	48.3
3	3	4	2	9	7.8
4	16	18	2	36	31.0
0	5	3	0	8	6.9
Total	38	37	41	116	100.0

Forty three out of the 56 ($10 + 9 + 37$) students who chose answer 2 wrote that electron flow is from the negative terminal of the battery to the positive terminal in the external circuit; seven wrote that the electron flows through the electrolyte; six others did not give any reason. Thirty one out of the 36 ($16 + 18 + 2$) students who chose answer 4 wrote that the electron flows from the negative terminal of the battery then continues to flow through the electrode Y and swims through the electrolyte. *This shows the students' alternative conception of electrons flowing in*

the electrolyte, similar to a finding by Sanger and Greenbowe (1997b). Five others did not give any reason.

SUMMARY

The second version of the free response instrument was administered to 116 secondary students (16 to 17 years old) from three classes M1, M2 and M3 of School X, Kuching in April, 2007. This group of students are the first batch following the new syllabus of the Malaysian Certificate Examination using English as the medium of instruction in Chemistry.

The findings highlight an initial pen-and-paper probe into the Form Four students' understanding of electrolysis. The data collected in this study form the alternative conceptions and non-conceptions of the students in the sample. The data collected were analysed and used to design the first version of the two-tier multiple choice diagnostic instrument, which will be discussed in the following chapter.

CHAPTER SIX

DEVELOPMENT OF THE TWO-TIER MULTIPLE-CHOICE DIAGNOSTIC INSTRUMENT ON ELECTROLYSIS: STUDY 3 AND 4

INTRODUCTION

The aim of Study 3 and Study 4 was to develop the two-tier multiple-choice diagnostic instrument on electrolysis. The data collected from Study 2 as described in Chapter 5 was used to design the first version of the two-tier multiple-choice instrument which consisted of 21 items (Appendix G1). In Study 3, Interview Two was carried out in September 2007 with 15 students from the classes of M1, M2 and M3 of School X, Kuching, Malaysia. Interview Two was a semi-structured interview carried out on students who showed alternative conceptions in their answers in Study 2. A copy of the interview protocol can be found in Appendix D2. The results of Study 2 together with the results from Interview Two made up the first version of the two-tier multiple choice test. This first version was sent to three senior chemistry teachers and two chemistry lecturers for further comments and improvement to the instrument. The changes made were described for each item and this resulted in 18 items. A copy of this first version can be found in Appendix G2. In Study 4, the improved instrument with 18 items was sent to one senior chemistry teacher and two chemistry lecturers for further comments and improvement to the instrument. The changes made were described for each item and subsequently produced the 17 items in the final two-tier multiple-choice diagnostic instrument on electrolysis.

STUDY 3: FIRST VERSION OF THE TWO-TIER MULTIPLE-CHOICE INSTRUMENT

The data obtained in Study 2 was used to design the first version of the two-tier diagnostic instrument. The reasons given by the students in the free response instrument in Study 2 were included as the reasons for the content choice chosen. Those students who showed alternative conceptions in their answers were

interviewed in September 2007 to gain further insight into their reasons chosen. A total of 15 students, with five students from each class of M1, M2 and M3 of School X, Kuching, Malaysia were interviewed for this purpose. In Table 6.1 the sources of the reasons are labelled as R for reason given in the free response test, while I stands for the reason given during the interview.

Development of the first version of the two-tier multiple-choice instrument

Multiple choice items which measured student understanding should have distractors based on the content, and students' alternative conceptions of a science idea. When the distractors were based on students' alternative views of the concepts, this method provided a more effective way to identify the students' alternative conceptions (Peterson, et al., 1989; Treagust, 1988).

Each item in the final diagnostic instrument consisted of two-tier multiple-choice responses. The first-tier of each item in the test is a multiple-choice content question with two or three choices. In this study, the first-tier is made consistent with two choices of 'True' and 'False' which is described below. The second-tier of each item contains a set of three or more possible reasons for the answer to the first-tier. Among the possible reasons, one will be the correct answer, the others are identified alternative conceptions, together with simple wrong answers.

The first-tier of the item

The content choice had two or more choices, some items had 'True' or 'False'. In Study 3, all 21 items were made consistent with the content choice as 'True' or 'False', with the justification that the concept tested in the stem of each item remains the same. Items 4, 5 and 13 are described in detail how the change was done.

Item 4

In the electrolysis of molten magnesium oxide using carbon electrodes, at which electrode is magnesium produced?

- *(1) At the cathode
- (2) At the anode

The stem of item 4 was changed to:

In the electrolysis of molten magnesium oxide using carbon electrodes, magnesium is produced at the anode.

- (A) True
- (B) False

The concept in the item was the same, asking at which electrode magnesium will be produced in the electrolysis of molten magnesium oxide using carbon electrodes. Instead of offering alternatives, the focus was on one of the content choices, “At the anode”. Students need to pause and think of where magnesium will be produced in the process before they can decide whether the statement is true or false.

Item 5

When aqueous iron(II) sulphate is electrolysed using platinum electrodes, what happens to the light green colour of the solution?

The colour of the solution

- *(1) becomes darker.
- (2) becomes fainter.
- (3) remains the same.

The stem was changed to:

When aqueous iron(II) sulphate is electrolysed using platinum electrodes, the light green colour of the solution becomes fainter.

- (A) True
- (B) False

The concept of the item was the same, asking about the change of colour of the solution. Instead of offering alternatives, the focus was on one of the content choices, “The colour of the solution becomes fainter”. The students have to pause and think of what are the possible changes before they can decide whether the statement is true or false.

Item 13

In order to purify an impure copper plate, which of the following must be used as the cathode?

- (1) An impure copper plate
- *(2) A pure copper plate
- (3) A carbon rod

The stem was changed to:

In order to purify an impure copper plate, a carbon rod must be used as the cathode.

- (A) True
- (B) False

Similarly, for item 13, the concept of the item was maintained, asking about which substance should be used as the cathode in order to purify an impure copper plate. Instead of offering alternatives, the focus was on one of the content choices “a carbon rod must be used”. Students have to think carefully of what are the possible substances before they can decide on whether the statement is true or false.

The second-tier of the item

Items 4 and 13 are explained in detail how the second-tier of each item in the first version of the two-tier multiple-choice instrument was formed.

Item 4

After choosing the content choice in the first-tier of the item, students were asked to give a reason for the content choice selected. The reasons given by the students for item 4 from the results in Study 2 were:

- (1) Magnesium ions move towards the anode.
- (2) Magnesium ions have negative charge, so they are attracted to the negative terminal.
- (3) Magnesium ions receive electrons that are released from the anode to produce magnesium metal at the cathode.
- (4) Magnesium ions are cations, so they are attracted to the cathode which is negatively charged.

These reasons were then included in preparing the second-tier of item 4 in the first version of the two-tier multiple-choice instrument.

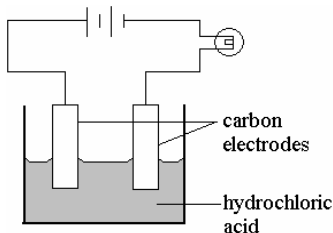
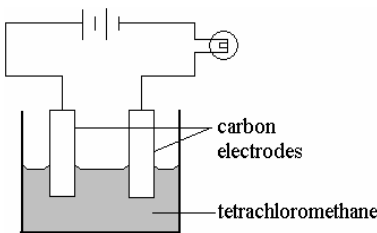
Item 13

Similarly, for item 13, after choosing the content choice, students were asked to give a reason for the content choice selected. The reasons given by the students from the results of Study 2 were:

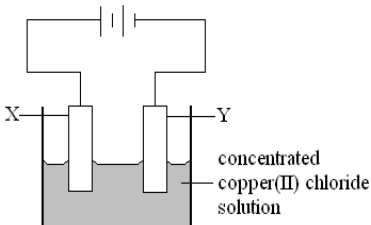
- (1) An impure copper plate must be used because copper ions from solution will receive electrons to form pure copper at cathode.
- (2) A pure copper plate must be used because copper ions from solution will receive electrons to form pure copper at cathode.
- (3) An impure copper plate must be used because electrons move from anode to cathode.
- (4) A carbon rod because impurities on the copper plate will be dissolved.

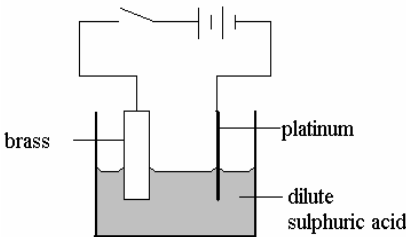
These reasons were then included in preparing the second-tier of item 13 in the first version of the two-tier multiple-choice instrument.

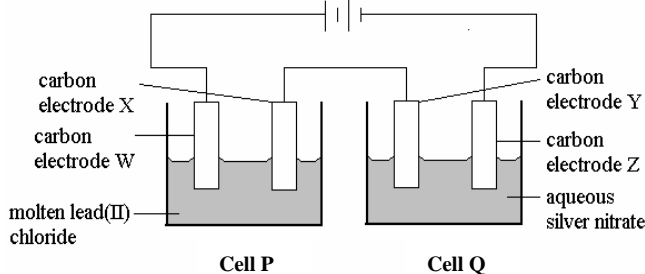
Table 6.1 Table of specifications for the first version of the two-tier multiple-choice diagnostic instrument (Appendix G1)

Item No.	Items, Reasons and Their Sources	General Areas of Sources of Alternative Conceptions
1	<p>In the following two experiments you would expect the bulb in Experiment 1 to light up.</p> <div style="display: flex; justify-content: space-around; align-items: flex-start;"> <div style="text-align: center;"> <p>Experiment 1</p>  </div> <div style="text-align: center;"> <p>Experiment 2</p>  </div> </div> <p>(A) True (B) False</p> <p>(1) Tetrachloromethane contains more ions. (R)</p> <p>(2) Tetrachloromethane is a covalent compound. (R)</p> <p>(3) Hydrochloric acid consists of free moving ions. (I, R)</p> <p>(4) Hydrochloric acid reacts with carbon electrodes to complete the circuit. (R)</p>	electrolyte, non electrolyte
<p>Note:</p> <p>Symbol Source of alternative conception</p> <p>I Interviews</p> <p>R Second version of free response test</p> <p>The correct reason is in bold</p>		
2	<p>During electrolysis of molten lead(II) bromide using graphite electrodes, reddish fumes of bromine gas and molten lead are produced. Oxidation occurs at the cathode.</p> <p>(A) True (B) False</p> <p>(1) Bromine ions move to the cathode, therefore oxidation occurs at the cathode. (R)</p> <p>(2) Bromide ions lose electrons to form bromine molecules at the anode. (R)</p> <p>(3) Lead ion is positive, it moves to the cathode. (R)</p> <p>(4) Oxygen is attracted to the anode. (R)</p>	electrolysis of molten compound, products of electrolysis, oxidation, loss of electrons
3	<p>In the manufacture of chlorine by electrolysis of concentrated aqueous sodium chloride using graphite electrodes, hydrogen gas is also produced.</p> <p>(A) True (B) False</p> <p>(1) Hydrogen ions are preferably discharged over hydroxide ions. (R)</p> <p>(2) Hydrogen ions are selectively discharged over sodium ions. (R)</p> <p>(3) Aqueous sodium chloride does not contain hydrogen ions. (R)</p> <p>(4) Only chlorine gas is released. (R)</p>	electrolysis of concentrated aqueous compound, products of electrolysis, selective discharge of ions

Item No.	Items, Reasons and Their Sources	General Areas of Sources of Alternative Conceptions
4	<p>In the electrolysis of molten magnesium oxide using carbon electrodes, magnesium is produced at the anode.</p> <p>(A) True (B) False</p> <p>(1) Magnesium ions move towards the anode. (R)</p> <p>(2) Magnesium ions have negative charge, so they are attracted to the negative terminal. (R)</p> <p>(3) Magnesium ions receive electrons that are released from the anode to produce magnesium metal at the cathode. (R)</p> <p>(4) Magnesium ions are cations, so they are attracted to the cathode which is negatively charged. (R)</p>	electrolysis of molten compound, cathode and anode, products of electrolysis
5	<p>When aqueous iron(II) sulphate is electrolysed using platinum electrodes, the light green colour of the solution becomes fainter.</p> <p>(A) True (B) False</p> <p>(1) Neither iron(II) ions nor sulphate ions are discharged. (R)</p> <p>(2) Hydrogen and hydroxide ions are discharged, but iron(II) ions are not discharged at cathode, hence the colour remains the same. (I, R)</p> <p>(3) Hydrogen and hydroxide ions are decreasing, thus concentration of solution increases and the colour becomes darker. (I, R)</p> <p>(4) Concentration of iron(II) ions decreases as iron gets deposited at the cathode, therefore the green colour of the solution becomes fainter. (I, R)</p>	electrolysis of aqueous compound, platinum electrodes, colour of electrolyte
6	<p>The products of electrolysis of dilute sulphuric acid using inert electrodes are hydrogen at cathode and oxygen at the anode.</p> <p>(A) True (B) False</p> <p>(1) Sulphuric acid releases sulphur dioxide. (R)</p> <p>(2) Sulphur dioxide is a cation, it gets deposited at the anode, whereas oxygen gas is an anion, so it gets deposited at the cathode. (R)</p> <p>(3) Contains hydrogen and oxygen ions. (R)</p> <p>(4) Hydrogen ions and hydroxide ions are selectively discharged. (R)</p>	electrolysis of aqueous compound, inert electrodes, products of electrolysis, cathode and anode, selective discharge of ions
7	<p>When aqueous zinc nitrate is electrolysed using graphite electrodes, effervescence occurs only at the cathode.</p> <p>(A) True (B) False</p> <p>(1) H⁺ and OH⁻ are selectively discharged over Zn²⁺ and NO₃⁻ ions. (R)</p> <p>(2) Hydrogen is released at cathode, thus effervescence occurs. (R)</p> <p>(3) Reaction occurs between zinc ions and the graphite electrodes. (R)</p> <p>(4) Zinc is deposited at the cathode. (R)</p>	electrolysis of aqueous compound, inert electrodes, products of electrolysis, cathode and anode, selective discharge of ions

Item No.	Items, Reasons and Their Sources	General Areas of Sources of Alternative Conceptions
8	<p>When dilute sulphuric acid is electrolysed using inert electrodes, the concentration of the electrolyte increases.</p> <p>(A) True (B) False</p> <p>(1) Hydrogen and oxygen are selectively discharged, so the concentration of acid decreases. (R)</p> <p>(2) H^+ from acid is discharged to form hydrogen gas, thus concentration of acid decreases. (I, R)</p> <p>(3) $4H^+$ and $4OH^-$ are released at the same time, so the concentration remains the same. (I, R)</p> <p>(4) OH^- and H^+ ions are discharged. Volume of water decreases thus concentration of the electrolyte increases. (R)</p>	electrolysis of aqueous compound, inert electrodes, concentration of electrolyte, products of electrolysis, selective discharge of ions
9	<p>Aqueous copper(II) sulphate is electrolysed using platinum electrodes, and a reddish-brown deposit is produced at the cathode. The blue colour of the electrolyte remains unchanged.</p> <p>(A) True (B) False</p> <p>(1) Copper(II) ions are discharged and deposited at the cathode, so the colour of the electrolyte decreases in intensity. (R)</p> <p>(2) Copper(II) ions are displaced by platinum ions, so the colour of the electrolyte decreases in intensity. (R)</p> <p>(3) Copper dissolves in the electrolyte, so the colour of the electrolyte increases in intensity. (R)</p> <p>(4) Platinum electrodes are inert, so the colour of the electrolyte remains the same. (R)</p>	electrolysis of aqueous compound, platinum electrodes, colour of electrolyte, products of electrolysis, cathode and anode, selective discharge of ions
10	<p>The diagram below shows an electrolytic cell in which an electric current passes through a concentrated aqueous solution of copper(II) chloride using inert graphite electrodes.</p>  <p>At electrode X, chloride ions are oxidised.</p> <p>(A) True (B) False</p> <p>(1) Copper(II) ions are attracted to X and reduced. (I, R)</p> <p>(2) Copper(II) ions are oxidised. Copper(II) ions are positive, X is negative. (R)</p> <p>(3) Chloride ions are oxidised. Chloride ions are being discharged because of higher concentration than hydroxide ions. (R)</p> <p>(4) Chloride ions are reduced at the cathode. Chloride ions are being discharged because of higher concentration than hydroxide ions. (I, R)</p>	electrolysis of concentrated aqueous solution, graphite electrodes, oxidation of ions, reduction of ions, factors affecting discharge of ions

Item No.	Items, Reasons and Their Sources	General Areas of Sources of Alternative Conceptions
11	<p>In order to electroplate a metal spoon with silver using silver nitrate as electrolyte, a silver strip should be used as the cathode.</p> <p>(A) True (B) False</p> <p>(1) A copper strip is suitable. (R)</p> <p>(2) The spoon is suitable as silver ions will be attracted to it at cathode. (I, R)</p> <p>(3) A carbon rod is suitable as cathode. (R)</p> <p>(4) The silver strip because only silver ions can electroplate the spoon. (I, R)</p>	electroplating of an object
12	<p>Brass is an alloy of copper (60%) and zinc (40%). The diagram shows the apparatus that is used to carry out electrolysis using brass as the anode.</p>  <p>When the circuit is first closed, zinc dissolves at the anode and hydrogen gas is liberated at the cathode.</p> <p>(A) True (B) False</p> <p>(1) Zinc and copper dissolve at the anode because zinc and copper are more electropositive than hydrogen. Copper is lower than zinc, copper ions from the anode is deposited as copper at the cathode. (R)</p> <p>(2) Zinc is more electropositive than copper. (R)</p> <p>(3) Copper dissolves at the anode and oxygen gas is liberated at the cathode as copper is lower than zinc. (R)</p> <p>(4) Copper dissolves at the anode and hydrogen gas is liberated at the cathode as copper is lower than zinc. (R)</p>	Electrolysis of dilute sulphuric acid, products of electrolysis, electrochemical series
13	<p>In order to purify an impure copper plate, a carbon rod must be used as the cathode.</p> <p>(A) True (B) False</p> <p>(1) An impure copper plate must be used because copper ions from solution will receive electrons to form pure copper at the cathode. (R)</p> <p>(2) A pure copper plate must be used because copper ions from solution will receive electrons to form pure copper at the cathode. (R)</p> <p>(3) An impure copper plate must be used because electrons move from the anode to the cathode. (R)</p> <p>(4) A carbon rod because impurities on the copper plate will be dissolved. (R)</p>	purification of metal, products of electrolysis, movement of electrons at cathode and anode

Item No.	Items, Reasons and Their Sources	General Areas of Sources of Alternative Conceptions
14	<p>The diagram below shows the set-up of apparatus to investigate the electrolysis of molten lead(II) chloride and aqueous silver nitrate.</p>  <p style="text-align: center;">Cell P Cell Q</p> <p>The electrode X will increase in mass.</p> <p>(A) True (B) False</p> <p>(1) Lead is a heavy metal which has high surface tension. (R)</p> <p>(2) Lead will be deposited at X, the cathode in Cell P. (R)</p> <p>(3) Silver will be collected at electrode Y. (R)</p> <p>(4) Silver will be collected at electrode Z, the cathode in Cell Q. (R)</p>	electrolysis of molten compound and aqueous compound, products of electrolysis
15	<p>In the extraction of aluminium by the electrolysis of molten aluminium oxide using graphite electrodes, the anode electrode has to be replaced periodically.</p> <p>(A) True (B) False</p> <p>(1) Anode dissolves to give aluminium ions to be discharged and deposited at the cathode. (R)</p> <p>(2) Oxygen gas reacts with carbon to form carbon dioxide, hence carbon electrode erodes over time. (R)</p> <p>(3) Electrode becomes smaller, as ions from the anode move to the cathode. (R)</p> <p>(4) To avoid overheating that will disrupt the extraction. (R)</p> <p>(5) Mass of the anode will decrease. (R)</p>	extraction of aluminium metal from molten aluminium oxide, products of electrolysis
16	<p>The use of electrolysis in industry causes pollution of the environment.</p> <p>(A) True (B) False</p> <p>(1) Electrolytic processes produce poisonous gases such as chlorine. (R)</p> <p>(2) Chloride ions are selectively discharged into the environment. (R)</p> <p>(3) Chemical wastes such as cadmium ions contaminate the water sources. (R)</p> <p>(4) Chemical wastes undergo proper treatment before they are released into the environment. (R)</p>	effect of electrolysis on environment
17	<p>In the motor industry, electroplated nickel or chromium is widely used as the coating system.</p> <p>(A) True (B) False</p> <p>(1) Nickel and chromium are cheap and affordable. (R)</p> <p>(2) The coating gives a shiny surface and can prevent rusting. (R)</p> <p>(3) Nickel and chromium are not suitable for electroplating. (R)</p> <p>(4) Nickel and chromium have high boiling and melting point. (R)</p>	electroplating in motor industry

Item No.	Items, Reasons and Their Sources	General Areas of Sources of Alternative Conceptions
18	<p>Cutlery items are often electroplated with silver alone, not with silver and nickel.</p> <p>(A) True (B) False</p> <p>(1) Silver is too expensive. (I, R)</p> <p>(2) Alloy is less brittle. (R)</p> <p>(3) To prevent from rusting. (I, R)</p> <p>(4) It will affect human health if electroplated with nickel. (R)</p>	electroplating of cutlery items
19	<p>Gold-plated wrist watches are more expensive than gold watches.</p> <p>(A) True (B) False</p> <p>(1) The process of electroplating is troublesome and complicated. (I, R)</p> <p>(2) Gold-plated is a thin layer of gold covering the object. (I, R)</p> <p>(3) Gold-plated is made up of gold metal, more gold is used. (I, R)</p> <p>(4) Gold-plated have better quality. (R)</p>	electroplating of gold watches
Items 20 and 21 refer to the diagram below.		
The diagram shows the electrolysis of molten magnesium oxide.		
<p>The diagram shows an electrolytic cell for molten magnesium oxide. A battery is connected to two carbon electrodes, X and Y. The battery has a positive terminal (R) and a negative terminal (S). Electrode X is connected to terminal R, and electrode Y is connected to terminal S. The electrolyte is molten magnesium oxide.</p>		
20.	<p>Electrode X is the anode.</p> <p>(A) True (B) False</p> <p>(1) Electrode X is connected to the negative terminal of the battery. (I, R)</p> <p>(2) Electrode X is connected to the positive terminal of the battery. (I, R)</p> <p>(3) X is positively charged, so negative ions move there to accept electrons. (I, R)</p> <p>(4) X is negatively charged, so positive ions move there to release electrons. (I, R)</p>	identifying the anode with respect to the terminal of the battery
21.	<p>The direction of the movement of electrons is from electrode Y to electrode X in the electrolyte.</p> <p>(A) True (B) False</p> <p>(1) Electrons flow from the negative terminal to the positive terminal of the battery. (I, R)</p> <p>(2) Electrons flow from the positive terminal to the negative terminal of the battery. (I, R)</p> <p>(3) It is the role of ions to carry the electrical charge from electrode Y to electrode X in the electrolyte. (R)</p> <p>(4) It is the role of ions to carry the electrical charge from electrode X to electrode Y in the electrolyte. (R)</p>	movement of electrons in electrolytic cell

Interview Two

All interviews were conducted during the free time of the students in the chemistry laboratory. That week the chemistry laboratory was available because the Form Six students who were using the laboratory were having their written examinations in their classrooms. The students for the interviews were chosen from three classes of M1, M2 and M3 of School X, Kuching, Malaysia who had answered the second version of the free response test with alternative conceptions illustrated in their reasons. The students were called out individually from their class and interviewed, based on a set of questions which can be found in Appendix D2. A transcript of the Interview Two with students S16 and S25 can also be found in Appendix E2.

Direction of the flow of electrons

Students S16, S17, S25 and S28 did not predict the direction of the flow of electrons correctly. Both students S16 and S28 identified the anode and cathode electrodes correctly, but did not predict the direction of the flow of electrons correctly. This is illustrated in the following excerpts of interview with Students S16 and S28. A summary of alternative conceptions and non-conceptions on the direction of the flow of electrons is shown in Table 6.2.

I: Can you please explain why you choose the direction of the flow of electrons is from X to Y in the electrolyte? Just explain in your own words.

S16: Eh...the direction of the...of the flow of electrons is from.... electrode X to electrode Y in the electrolyte because the movement of the electrons must... from the anode to the cathode which is positive to the negative terminal.

I: Positive to negative.... Right, can you show me where is the positive?

S16: This is positive (electrode X, pointing to the diagram), this is negative (electrode Y), follow the battery.

I: Can you please explain why the direction of flow of electrons is from electrode X to electrode Y (in the electrolyte)? You mean this way? Can you explain why you chose this direction?

S28: Because carbon electrode X is the anode which release electrons... into the molten magnesium oxide. The electrons released are then received by the cathode, that is, the carbon electrode Y.

- I: How are the electrons received by the cathode?
- S28: Hm...the electrons... swim through the electrolyte.
- I: You have chosen which electrode to be the anode here?
- S28: X.
- I: Okay, so your reason is....
- S28: Because it is connected to the positive terminal of the battery.

Table 6.2 Alternative conceptions and non-conceptions on the direction of the flow of electrons

Alternative Conceptions	Non-conceptions
1. Electrons flow from the positive terminal of the battery to the negative terminal through the electrolyte.	
2. Electrons swim through the electrolyte.	

Ions present in the solution

Students S18, S27, and S29 predicted the colour of the solution to remain the same; Students S19, S20, and S30 predicted the colour of the solution to become darker whereas Students 23 and 25 predicted the colour to become fainter. Student S19 predicted the change of colour correctly but did not justify it correctly, with the explanation that the darker colour is due to the presence of iron(III) ions and this is a misconception. Student S19 also had the misconception that platinum is one of the ions present in the solution. Student S23 listed all the ions present except hydrogen ions, and this student also showed the misconception that the colour becomes fainter due to the iron(II) ions accepting electrons to become iron. Student S27 showed poor understanding of ions in aqueous solutions, stating that the change to a fainter colour was because there was no displacement of ions. This is illustrated in the following excerpts with Students S19, S23 and S27. A summary of alternative conceptions and non-conceptions on the ions present in the solution is shown in Table 6.3.

- I: When aqueous iron(II) sulphate is electrolysed using platinum electrodes, what happens to the light green colour of the solution?
- S19:I choose the first one. ...It becomes darker.

I: What is your reason for that?

S19: Because iron(II) in iron(II) sulphate..... is being oxidised.

I: What is iron(II) ions oxidised to?

S19: ...to iron(III) ions.

I: Now can you tell me what are the ions present in this solution? Ions, all those ions present in this solution?

S19:Sulphate?

I: Sulphate, what else?

S19: Iron.

I: Any more? Is that all?

S19:Platinum.

I: Platinum, okay, is that all?

S19: Yes.

I: Regarding the electrolysis of aqueous iron(II) sulphate using platinum electrodes, what happens to the light green colour of the solution?

S23: It becomes fainter.

I: Why do you think it becomes fainter?

S23: Because the concentration of iron(II) ions decreases when they accept electrons to become iron metal.

I: Iron metal, ...can you tell me what other ions are present here?

S23: Iron...iron(II), hydroxide ions...

I: What else, ...anymore?

S23: Sulphate ions.

I: Good, you have listed the ions. Why do you think iron(II) will be chosen?

S23: Because it's more electropositive.

I: In the electrolysis of aqueous iron(II) sulphate using platinum electrodes, what happens to the light green colour of the solution?

S27: I think the colour of the solution will remain the same.

- I: You mentioned that the colour will remain the same. What is your reason for that?
- S27: There is no...displacement of ions taking place.

Table 6.3 Alternative conceptions and non-conceptions on the ions present in the solution

	Alternative Conceptions	Non-conceptions
1.	The light green colour of iron(II) sulphate solution becomes darker because iron(II) ions in iron(II) sulphate is oxidised to iron(III).	
2.	The light green colour of iron(II) sulphate solution becomes fainter because iron(II) ions accept electrons to become iron.	
3.	Platinum is one of the ions present in the solution.	

Concentration of the electrolyte

Students S19, S21 and S25 thought that the concentration of the electrolyte remains unchanged while Students S20, S22 and S26 thought that the concentration decreased. Student S21 displayed the misconception that inert electrodes will not affect the concentration of the electrolyte. Student S22 gave the explanation that there is a decrease in hydrogen ions, consequently a decrease in the concentration of the electrolyte, displaying the misconception that a decrease in the concentration of hydrogen ions will decrease the concentration of the electrolyte. Excerpts of Students S21 and S22 are shown below. A summary of alternative conceptions and non-conceptions on the concentration of dilute sulphuric acid using inert electrodes is shown in Table 6.4.

- I: Now let's talk about the electrolysis of dilute sulphuric acid. This one you have studied in your lesson, right?

S21: Yes.

- I: What happens to the concentration of the electrolyte?

S21: Remains unchanged.

- I: Okay, ..remains unchanged. So what is your reason?

S21: Because electrolyse dilute sulphuric acid using inert electrodes will not affect the concentration of the electrolyte.

- I: Aha, I see. What are the ions present here?
- S21: Hydrogen and sulphate ions.
- I: Okay, hydrogen and sulphate ions. Is there any other ions?
- S21: (Pause)... Hydroxyl ion.
- I: Now let's talk about when dilute sulphuric acid is electrolysed using inert electrodes, what happens to the concentration?
- S22: It...it decreases.
- I: What is your main reason for that?
- S22: The hydrogen ions are being selectively discharged to produce hydrogen gas, so concentration of hydrogen ions in the electrolyte decreases, hence concentration of electrolyte decreases.

Table 6.4 Alternative conceptions and non-conceptions on the concentration of dilute sulphuric acid using inert electrodes

Alternative Conceptions	Non-conceptions
1. Inert electrodes will not affect the concentration of the electrolyte.	
2. A decrease in the concentration of hydrogen ions will result in the decrease in the concentration of the electrolyte.	

Ions moving to the electrode X (anode)

Students S19 and S30 explained that copper ions move to the anode X and are reduced, displaying the misconception that cations move to the anode whereas Students S24 and S25 thought that chloride ions move to the anode X and are reduced, displaying the misconception that anions are reduced at the anode. Excerpts of Students S19, S24 and S25 are shown below. A summary of alternative conceptions and non-conceptions on the ions moving to the anode (positive electrode) is shown in Table 6.5.

- I: Now when an electric current passes through a concentrated aqueous solution of copper(II) chloride using graphite electrodes, what happens at electrode X?
- S19:Copper(II) ions are reduced.
- I: What is electrode X here? Is it anode or cathode?
- S19: Anode.

- I: Copper ions are reduced. What makes you think that it's being reduced?
- S19: (A long pause).....Because... copper(II) ions move to the anode and accept electrons.
- I: Now for this,if an electric current passes through a concentrated aqueous solution of copper(II) chloride using graphite electrodes, now what happens at electrode X?
- S24: The chloride ions are reduced.
- I: Are reduced.... Which terminal is that? Electrode X is what?
- S24: The anode.
- I: Oh, the electrode X is anode. So if you say chloride ions are reduced, can you explain why?
- S24: Because the chloride ions are attracted toward anode and then they undergo reduction.
- I: Now for a concentrated aqueous solution of copper(II) chloride, what are the ions present?
- S25: The copper ion, chloride... ions, hydroxide and... hydrogen ions.
- I: What happens to the chloride ions?
- S25: The chloride ions are reduced.
- I: Why do you say that the chloride ions are reduced?
- S25: Because em....the chloride ions is the negative ion, so it is attracted to the positive which is the anode. And then, in order to become,....in order to... make less of the charges, so it has to gain electrons... to be reduced.

Table 6.5 Alternative conceptions and non-conceptions on the ions moving to the anode (positive electrode)

Alternative Conceptions	Non-conceptions
1. Copper(II) ions are reduced at the anode.	
2. Cations move to the anode.	
3. Chloride ions are reduced at the anode.	

The choice of cathode to electroplate a metal spoon with silver

Student S17 suggested using a silver strip as the cathode for electroplating a metal spoon with silver. The excerpt of Student S17 is shown below. A summary of alternative conceptions and non-conceptions on choice of cathode to electroplate a metal spoon is shown in Table 6.6.

I: If you want to electroplate a metal spoon with silver, which of the following would you use as the cathode?

S17: Silver strip.

I: Why do you think is the silver strip?

S17: Because it will dissolve and become ions and replace the elect...electrolyte that will go and coat the spoon.

I: Now, which ions will move to the spoon?

S17: Ah...ions?Silver ions.

Table 6.6 Alternative conceptions and non-conceptions on choice of cathode to electroplate a metal spoon

Alternative Conceptions	Non-conceptions
1. Silver strip is used as the cathode to electroplate a metal spoon.	

Electroplating cutlery items

Student S17 explained that silver is used in electroplating but not with nickel because nickel is not an ionic substance, with the misconception that covalent bonding is present in nickel whereas Student S21 considered that using silver and nickel will make the cutlery items more brittle. The excerpts of Students S17 and S21 are shown below. A summary of alternative conceptions and non-conceptions on electroplating cutlery items is shown in Table 6.7.

I: Cutlery items are often electroplated with silver alone, not with silver and nickel. Is that true or false?

S17: True.

I: Why do you think so?

S17: Because ...ah...nickel is not an ionic substance.

I: So what type of bonding do you think is present in nickel?

S17: Covalent.

I: What about cutlery items, are they often electroplated with silver and nickel?

S21: No.

- I: What is your reason for that?
- S21: Because...(thinking)... the cutlery items will become more brittle.

Table 6.7 Alternative conceptions and non-conceptions on electroplating cutlery items

Alternative Conceptions		Non-conceptions
1.	Covalent bonding is present in nickel.	Electroplating cutlery items with silver will be more expensive.
2.	Electroplating with silver and nickel will make the cutlery items more brittle.	

Electroplating gold watches

Students S16, S21 and S28 considered gold-plated watches to be more expensive than gold watches. Excerpts of Students S16, S21 and S28 are shown below. A summary of alternative conceptions and non-conceptions on electroplating gold watches is shown in Table 6.8.

- I: Now how much do you know about gold-plated wrist watches... are they more expensive than gold watches?
- S16: True, yes.
- I: What makes you think so?
- S16: Because it is more pure than the gold watches and does not mix with other metal.
- I: (to confirm) Gold-plated wrist watches are more pure, right?
- S16: Yes.
- I: Talking about gold-plated wrist watches, are they more expensive than gold watches?
- S21: Yes.
- I: What makes you think so?
- S21: Because it pays the extra process electroplating, to electroplate it makes it more expensive.
- I: What makes you think that gold-plated wrist watches are more expensive than gold watches?
- S28: Because a lot of energy is needed for the process of electrolysis to coat the watches with gold and gold is very difficult to undergo electrolysis.

Table 6.8 Alternative conceptions and non-conceptions on electroplating gold watches

Alternative Conceptions	Non-conceptions
1. Gold-plated watches are more expensive than gold watches.	Gold is very difficult to undergo electrolysis.

Table 6.9 Alternative conceptions determined in Study 2 and Interview Two

Direction of the flow of electrons	
1.	Electron flows from the positive terminal of the battery to the negative terminal through the electrolyte.
2.	Electron swims through the electrolyte.
Ions present in the solution	
1.	The light green colour of iron(II) sulphate solution becomes darker because iron(II) ions in iron(II) sulphate is oxidised to iron(III).
2.	The light green colour of iron(II) sulphate solution becomes fainter because iron(II) ions accept electrons to become iron.
3.	Platinum is one of the ions present in the solution.
Concentration of the electrolyte	
1.	Inert electrodes will not affect the concentration of the electrolyte.
2.	A decrease in the concentration of hydrogen ions will result in the decrease in the concentration of the electrolyte.
Ions moving to the anode (positive electrode)	
1.	Copper(II) ions are reduced at the anode.
2.	Cations move to the anode.
3.	Chloride ions are reduced at the anode.
Choice of cathode to electroplate a metal spoon	
1.	Silver strip is used as the cathode to electroplate a metal spoon.
Electroplating cutlery items	
1.	Electroplating with silver and nickel will make the cutlery items more brittle.
2.	Nickel is not an ionic substance.
Electroplating gold watches	
1.	Gold-plated watches are more expensive than gold watches.
2.	Gold is very difficult to undergo electrolysis.

Refinement of the first version of the two-tier multiple-choice diagnostic instrument

The first version of the two-tier multiple-choice diagnostic instrument was sent to three senior chemistry teachers Mrs. F, Mrs. G, and Mrs. H and two chemistry lecturers Mrs. J and Ms K for further comments and improvement to the instrument. Many of the responses were rephrased. Items 12, 14 and 21 were deleted and this resulted in 18 items (Appendix G2). The changes made to each item is described below.

Item 1

The stem was rephrased as ‘In the two experiments below we would expect the bulb to light up only in Experiment 1’. Reason (4) was replaced with ‘The carbon anode dissolves producing ions.’ Item 1 stays as Item 1 in the second version of the two-tier electrolysis diagnostic instrument. From now on, the second version of the two-tier electrolysis diagnostic instrument will be referred to as ‘the second version of 2tEDI’.

Item 2

The stem was rephrased as ‘During electrolysis of molten lead(II) bromide using graphite electrodes, reddish fumes of bromine gas and molten lead are produced’. The phrase ‘Oxidation occurs at the cathode’ was deleted. Reasons (1), (2) and (3) were rephrased. Reason (1) was changed to ‘Bromide ions move to the cathode and are oxidised.’ Reason (2) was rephrased as ‘Bromide ions donate electrons at the anode and form bromine molecules’. Reason (3) was changed to ‘Lead(II) ions are positively charged and so move to the anode’. Item 2 becomes Item 4 in the second version of 2tEDI.

Item 3

Only reason (4) was changed to ‘The concentration of hydrogen ions is very low’. Item 3 becomes Item 13 in the second version of 2tEDI.

Item 4

All the four reasons were rephrased. Reason (1) was changed to 'Magnesium ions are attracted to the anode and accept electrons.' Reason (2) was changed to 'Magnesium ions are attracted to the cathode and donate electrons.' Reason (3) was changed to 'Magnesium ions are attracted to the anode and donate electrons.' Reason (4) was changed to 'Magnesium ions are attracted to the cathode and accept electrons.' Item 4 becomes Item 3 in the second version of 2tEDI.

Item 5

Reason (1) was partially rephrased to 'Neither iron(II) ions nor sulphate ions are discharged, so the concentration of the solution remains unchanged.' Reason (2) was changed to 'Hydrogen ions and hydroxide ions are discharged, so the concentration of the solution remains unchanged.' Reason (3) was replaced with 'Hydrogen ions and hydroxide ions are discharged, so the concentration of the solution increases.' Reason (4) was changed to 'The concentration of iron(II) ions decreases as iron is deposited at the cathode.' Item 5 stays as Item 5 in the second version of 2tEDI.

Item 6

The stem of the item was improved with 'the' added before cathode, and 'the' added before anode. All the four reasons were rephrased. Reason (5) was added. Reason (1) was rephrased as ' SO_4^{2-} and H^+ ions are selectively discharged.' Reason (2) as ' SO_4^{2-} and OH^- ions are selectively discharged.' Reason (3) was changed to 'The electrolyte consists of hydrogen ions and oxygen ions.' Reason (4) was rephrased as ' H^+ and OH^- ions are selectively discharged.' Reason (5) 'No reaction occurs because platinum electrodes are inert' was added to the list. Item 6 stays as Item 6 in the second version of 2tEDI.

Item 7

Part of the stem 'effervescence occurs' was changed to 'bubbles of gas are given off' to make sure the students understand the item correctly. Only reason (2) was changed to 'Hydrogen ions are discharged at the cathode, producing hydrogen gas' again eliminating the term 'effervescence' used. Item 7 becomes Item 10 in the second version of 2tEDI.

Item 8

Reason (2) was changed to 'H⁺ and SO₄²⁻ ions from the acid are selectively discharged, so the concentration of the acid decreases.' Reason (3) was partially changed to 'H⁺ and OH⁻ ions are discharged at the same time, so the concentration remains the same.' Reason (4) was partially changed to 'OH⁻ and H⁺ ions are discharged, effectively removing water molecules from the electrolyte.' Item 8 becomes Item 7 in the second version of 2tEDI.

Item 9

The stem of the item was improved with the words 'When' and 'At the same time' added. Reasons (1), (3) and (4) are improved by adding 'the' at the relevant places. Reason (2) was improved by rephrasing 'platinum' as 'platinum atoms' to avoid students misinterpreting 'platinum' as 'platinum ions'. Item 9 becomes Item 8 in the second version of 2tEDI.

Item 10

All the four reasons were rephrased as:

- (1) Cu²⁺ ions move to X and accept electrons.
- (2) Cu²⁺ ions move to X and give up electrons.
- (3) Cl⁻ ions move to X and accept electrons.
- (4) Cl⁻ ions move to X and give up electrons.

The changes made were aimed to test students about copper(II) ions and chloride ions and what happens to these ions at the electrode X. Item 10 becomes Item 9 in the second version of 2tEDI.

Item 11

The stem was improved by adding 'aqueous' to silver nitrate, and the last phrase changed to 'the spoon should be used as the anode'. All four reasons were rephrased as

- (1) Ag⁺ ions are attracted to the anode and selectively discharged.
- (2) Ag⁺ ions are attracted to the cathode and selectively discharged.
- (3) H⁺ ions present in water are attracted to the cathode and selectively discharged.
- (4) H⁺ ions present in water are attracted to the anode and selectively discharged.

Item 11 stays as Item 11 in the second version of 2tEDI.

Item 12

Item 12 was deleted as there was a wide range of possible reasons, and it would not serve the purpose of testing.

Item 13

The stem of the item was improved by rephrasing it as 'In order to purify an impure copper plate using aqueous copper(II) sulphate, a pure copper plate must be used as the cathode'. All four reasons were rephrased to

- (1) Cu^{2+} ions are attracted to the anode and selectively discharged.
- (2) Cu^{2+} ions are attracted to the cathode and selectively discharged.
- (3) H^+ ions present in water are attracted to the cathode and selectively discharged.
- (4) H^+ ions present in water are attracted to the anode and selectively discharged.

Item 13 becomes Item 12 in the second version of 2tEDI.

Item 14

The four reasons were rephrased as

- (1) Electrode Y dissolves in the electrolyte.
- (2) Electrode W becomes coated with lead.
- (3) Electrode Y becomes coated with silver.
- (4) Electrode Z becomes coated with silver.

Item 14 was deleted as there were too many concepts being tested.

Item 15

The 'anode electrode' in the stem of the item was rephrased as 'graphite anode'. All four reasons were rephrased. Reason (5) was deleted.

- (1) The anode dissolves in the hot molten aluminium oxide.
- (2) The oxygen produced at high temperatures oxidises the anode.
- (3) The cathode dissolves in the hot molten aluminium oxide.
- (4) The chlorine produced at high temperatures oxidises the cathode.

Item 15 becomes Item 14 in the second version of 2tEDI.

Item 16

Reason (1) was deleted as chlorine produced is an obvious poisonous gas; reason (2) was changed to ‘Gases such as hydrogen and oxygen are released into the atmosphere’ and became reason (1); reason (3) was rephrased as ‘Heavy metal ions such as cadmium and nickel ions are released into water resources’ and remains as reason (3); reason (4) was rephrased as ‘Chemical wastes are released into the environment after proper treatment’ and became reason (2).

Item 16 becomes Item 15 in the second version of 2tEDI.

Item 17

The stem of the item was rephrased as ‘In the motor industry, electroplated nickel and chromium are widely used as the coating system’. Reasons (1), (2), (3) and (4) were rephrased as

- (1) The metals are cheap and affordable.
- (2) The metals produce a shiny surface and can prevent rusting.
- (3) The metals do not form a strongly adhering coating.
- (4) The metals have high boiling and melting points.

Item 17 becomes Item 16 in the second version of 2tEDI.

Item 18

Reason (2) was rephrased as ‘The alloy is less brittle’. Reason (3) was improved by adding ‘cutlery’ in the phrase. Reason (4) was changed to ‘Nickel is poisonous’. Item 18 becomes Item 17 in the second version of 2tEDI.

Item 19

All four reasons were rephrased to

- (1) The process of gold-plating is complicated and time-consuming.
- (2) Gold-plated watches are coated with a thin layer of gold.
- (3) Gold-plated watches require more gold than gold watches.
- (4) Gold-plated watches are more attractive than gold watches.

Item 19 becomes Item 18 in the second version of 2tEDI.

Item 20

Reasons (1) and (2) were changed to 'Positive ions move to X and accept electrons' and 'Negative ions move to X and donate electrons' respectively. Reason (3) was rephrased to 'Positive ions move to Y and donate electrons'. Reason (4) was rephrased as 'Negative ions move to Y and accept electrons'. Item 20 becomes Item 2 in the second version of 2tEDI.

Item 21

The reasons were varied and it might not test the students as what was expected, so item 21 was deleted.

STUDY 4: REFINEMENT OF THE SECOND VERSION OF THE TWO-TIER MULTIPLE-CHOICE DIAGNOSTIC INSTRUMENT

The second version of the two-tier multiple-choice diagnostic instrument (Appendix G2) was sent to one senior chemistry teacher and two chemistry lecturers for further comments and improvement to the instrument. Most of the responses were maintained except for minor changes to items 1, 2, 3, 6, 7, 9, 10, 11, 12, 16 and 17. Of the total 18 items, only Item 18 was deleted. This resulted in the final version of two-tier electrolysis diagnostic instrument (EDI) with 17 items which can be found in Appendix H.

Item 1

The formula CCl_4 was added to tetrachloromethane in reasons (1) and (2), and HCl was added to hydrochloric acid in reason (3) because students may be more familiar with the formula than the name of the compound.

Item 2

All the four reasons were rephrased to

- (1) Positive ions move to X and accept electrons.
- (2) Negative ions move to X and donate electrons.
- (3) Positive ions move to Y and donate electrons.
- (4) Negative ions move to Y and accept electrons.

This was to test the students on the movement of ions and what happens at the anode with respect to electrons.

Item 3

‘Positively charged magnesium ions’ in all the four responses were changed to ‘Magnesium ions’, without giving any clue to the type of charged ions of magnesium, thus students have to know the correct type of charge. The phrase ‘give up electrons’ in reason (2) and (3) were replaced with ‘donate electrons’ to be consistent with what the students have been taught.

Item 6

In reason (1), the phrase ‘ SO_4^{2-} and H^+ ions’ was replaced with ‘Sulphate and hydrogen ions’ to avoid confusion with the formula of ions. Similarly, in reason (2), ‘ SO_4^{2-} and OH^- ions’ was replaced with ‘Sulphate and hydroxide ions’, and in reason (4), ‘ H^+ and OH^- ions’ was replaced with ‘Hydrogen and hydroxide ions’. Reason (5) ‘No reaction occurs because platinum electrodes are inert’ was added.

Item 7

The formula of the ions in reasons (2), (3), and (4) were all replaced with words. H^+ in reason (2) was replaced with ‘hydrogen ions’, H^+ and OH^- in reasons (3) and (4) were replaced with ‘hydrogen and hydroxide ions’.

Item 9

In reason (1) and (2), ‘ Cu^{2+} ions’ was replaced with ‘Copper(II) ions’, whereas in reason (3) and (4), ‘ Cl^- ions’ was replaced with ‘Chloride ions’. The phrase ‘give up electrons’ in reason (2) and (4) was changed to ‘donate electrons’ to be consistent with what the students are being taught in schools.

Item 10

In reason (1), H^+ , OH^- , Zn^{2+} and NO_3^- ions are replaced with the words ‘hydrogen, hydroxide, zinc and nitrate ions’ respectively to be more consistent with the all the other reasons.

Items 11 and 12 help to evaluate understanding of the similar principles involved in electroplating and metal purification by electrolysis.

Item 11

The phrase ‘a metal spoon’ in the stem of item 10 was replaced with ‘an iron spoon’ in order to be more specific on the type of spoon used. In reason (1) and (2), ‘Ag⁺ ions’ was replaced with ‘Silver ions’, whereas in reason (3) and (4), the phrase ‘H⁺ present in water’ was replaced with ‘Hydrogen ions’ because ‘water’ might confuse the students.

Item 12

The phrase ‘Cu²⁺ ions’ in reason (1) and (2) was replaced with ‘Copper(II) ions’ and became reason (3) and (4) respectively in the final version. In reason (3) and (4), the phrase ‘H⁺ ions present in water’ was replaced with ‘Hydrogen ions’ and became reason (1) and (2) respectively in the final version.

Item 15

Reason (1) was replaced with ‘Gases such as hydrogen and oxygen are released into the atmosphere’. Reason (3) was changed to become reason (2) in the final version as it is a shorter statement. In reason (2) of the draft, the phrase ‘chemical wastes such as cadmium and nickel ions’ is replaced with ‘heavy metal ions such as cadmium and nickel’ to emphasise the nature of the ions, and this became reason (3) in the final version.

Item 16

The stem of item 16 was further improved to ‘In the motor industry, the metals nickel and chromium are used for electroplating’ to give a clearer idea. Reason (1) was changed to ‘The metals are chemically unreactive’ and became reason (4) in the final version; reason (2) was simplified to ‘The metals prevent rusting’ and became reason (3) in the final version; reason (3) was rearranged as reason (2) in the final version; and reason (4) was rearranged as reason (1) in the final version.

Item 17

The stem was changed to ‘Cutlery items are often electroplated with silver and nickel’, and reasons (1), (2), (3) and (4) were changed to

- (1) Nickel reacts readily with silver.
- (2) Silver and nickel are expensive metals.
- (3) The cutlery becomes more brittle.
- (4) The cutlery becomes more resistant to corrosion.

Item 18 was deleted because all the reasons can be possible answers. This led to the final version with 17 items, a copy of which can be found in Appendix H. A table of specifications for the 17 items final version of the electrolysis diagnostic instrument (EDI) is shown in Table 6.10.

Table 6.10 Table of specifications for the 17 items final version of the electrolysis diagnostic instrument (EDI)

Item No.	Concepts Tested	Propositional Knowledge Statements	Possible Alternative Conceptions
1	Electrolyte and non-electrolyte	1, 2, 3	Tetrachloromethane contains more ions; Tetrachloromethane consists of free moving ions; The carbon anode dissolves producing ions.
2	Electrodes: Anode and cathode	7, 10, 13, 15, 16	Positive ions move to the anode and accept electrons; Positive ions move to the cathode and donate electrons; Negative ions move to the cathode and accept electrons.
3	Electrolysis of molten magnesium oxide	13, 15, 16, 17	Magnesium ions are attracted to the anode and accept electrons; Magnesium ions are attracted to the cathode and donate electrons; Magnesium ions are attracted to the anode and donate electrons.
4	Electrolysis of molten lead(II) bromide	13, 15, 16, 18, 19	Bromide ions move to the cathode and are oxidised; Lead(II) ions are positively charged and so move to the anode; Oxygen is attracted to the anode.
5	Electrolysis of aqueous iron(II) sulphate using platinum electrodes	21, 22, 23, 24, 25	Neither iron(II) ions nor sulphate ions are discharged, so the concentration of the solution remains unchanged; Hydrogen ions and hydroxide ions are discharged, so the concentration of the solution remains unchanged; The concentration of iron(II) ions decreases as iron is deposited at the cathode.

Item No.	Concepts Tested	Propositional Knowledge Statements	Possible Alternative Conceptions
6	Products of electrolysis of dilute sulphuric acid using inert electrodes	22, 23, 24, 25, 26	Sulphate and hydrogen ions are selectively discharged; Sulphate and hydroxide ions are selectively discharged; The electrolyte consists of hydrogen ions and oxygen ions; No reaction occurs because platinum electrodes are inert.
7	Change to the concentration of electrolyte during electrolysis of dilute sulphuric acid using inert electrodes	25, 26, 27	Hydrogen and oxygen ions are selectively discharged, so the concentration of the acid decreases; Hydrogen and sulphate ions are selectively discharged, so the concentration of the acid decreases; Hydrogen and hydroxide ions are selectively discharged, so the concentration of the acid remains the same.
8	Electrolysis of aqueous copper(II) sulphate using platinum electrodes	28, 29, 30, 32	Copper(II) ions are displaced by platinum, so the colour of the electrolyte decreases in intensity; Platinum dissolves in the electrolyte, so the colour of the electrolyte increases in intensity; Platinum electrodes are inert, so the colour of the electrolyte remains the same.
9	Electrolysis of concentrated aqueous solution of copper(II) chloride using graphite electrodes	7, 19, 23, 24, 25	Copper(II) ions move to the anode and accept electrons; Copper(II) ions move to the anode and donate electrons; Chloride ions move to the anode and accept electrons.
10	Electrolysis of aqueous zinc nitrate using graphite electrodes	23, 24, 25	Hydrogen ions are discharged at the cathode, producing hydrogen gas; Reaction occurs between zinc ions and the graphite electrodes; Zinc is deposited at the cathode.
11	Electroplating an iron spoon	12, 37, 39	Silver ions are attracted to the anode and selectively discharged; Hydrogen ions are attracted to the cathode and selectively discharged; Hydrogen ions are attracted to the anode and selectively discharged.
12	Purifying an impure copper plate	12, 22, 23, 24, 36	Hydrogen ions are attracted to the cathode and selectively discharged; Hydrogen ions are attracted to the anode and selectively discharged; Copper(II) ions are attracted to the anode and selectively discharged.
13	Manufacture of chlorine	22, 23, 24	Hydrogen ions are preferably discharged over hydroxide ions; Aqueous sodium chloride does not contain hydrogen ions; The concentration of hydrogen ions is very low.

Item No.	Concepts Tested	Propositional Knowledge Statements	Possible Alternative Conceptions
14	Extraction of aluminium metal from molten aluminium oxide using graphite electrodes	10, 15, 16, 35	The anode dissolves in the hot molten aluminium oxide; The cathode dissolves in the hot molten aluminium oxide; The oxygen produced at high temperatures oxidises the cathode.
15	Effect on the environment by the use of electrolysis in industry	41	Gases such as hydrogen and oxygen are released into the atmosphere; Chemical wastes are released into the environment after proper treatment.
16	Electroplating in the motor industry	38	The metals have high boiling and melting points; The metals do not form a strongly adhering coating; The metals are chemically unreactive.
17	Electroplating on cutlery items	38	Nickel reacts readily with silver; Silver and nickel are expensive metals; The cutlery becomes more brittle.

SUMMARY

Students who showed alternative conceptions in their answers to the free response instrument in Study 2 were interviewed to gain further insight into their reasons chosen. The interview was conducted in Interview Two in Study 3. The first version of the two-tier multiple-choice instrument which consisted of 21 items after a review by three senior chemistry teachers and two chemistry lecturers was reduced to 18 items. Changes made to the items were discussed. A further review in Study 4 by one senior chemistry teacher and two chemistry lecturers subsequently produced the 17 items in the final two-tier multiple-choice electrolysis diagnostic instrument (EDI). A copy of the electrolysis diagnostic instrument (EDI) is found in Appendix H. This instrument was used in the main study with 330 Form Four chemistry students in Kuching, Malaysia in October and November, 2007 and this will be discussed in the next chapter.

CHAPTER SEVEN

DEVELOPMENT, ADMINISTRATION AND ANALYSIS OF A TWO-TIER MULTIPLE-CHOICE DIAGNOSTIC INSTRUMENT

INTRODUCTION

This chapter addresses the development of a diagnostic instrument for use in assessing secondary school chemistry students' understanding of electrolysis concepts and to identify associated alternative conceptions that are held by the students.

The first version of the two-tier diagnostic instrument consisted of 21 multiple-choice items. The main features of two-tier multiple-choice diagnostic instruments are the convenience and ease with which they are administered and marked (Treagust, 1986, 1995). The instruments should therefore consist of a limited number of items, otherwise it would be too time consuming to administer and analyse. The second draft of the two-tier diagnostic instrument consisted of 18 items. The final diagnostic instrument which consisted of 17 items is the focus of discussion in this chapter.

The development of the final version of a two-tier multiple-choice diagnostic instrument containing 17 items is first discussed in this chapter. The administration of the instrument to 330 Form Four students is then described followed by statistical analyses of students' responses to the items. This is followed by an item analysis of the 17 items in order to highlight students' understanding of the reactions in electrolysis, including any alternative conceptions that may be held by them. The chapter concludes with a list of students' alternative conceptions that have been identified.

Development of Diagnostic Instrument

The 17 items for the final diagnostic instrument were developed based on the item analysis of students' responses to the first version of the two-tier diagnostic instrument that consisted of 21 items and feedback on the second version that consisted of 18 items. In the first version, some of the items were adopted as originally designed while others were modified by changing the responses and/or the reasons. Three items were deleted. Item 12 involving the electrolysis of dilute sulphuric acid using brass as the anode was deleted because it was testing too many concepts. Similarly, item 14 testing relating to the electrolysis of molten lead(II) chloride and aqueous silver nitrate was deleted for the same reason. Item 21 which involved understanding of the direction of electron flow in a circuit was deleted as the concept was incorporated in item 20. A copy of the second version diagnostic instrument with 18 items is found in Appendix G2 and the final electrolysis diagnostic instrument with 17 items completed in October 2007 is found in Appendix H.

Table 7.1 Relating items in diagnostic instrument to items in first version instrument

Final Version of Diagnostic Instrument	Draft Instrument	Amendments
Item 1	Item 1	-
Item 2	Item 20	Changed all reasons
Item 3	Item 4	Changed all reasons
Item 4	Item 2	Changed reasons 2 and 3
Item 5	Item 5	Changed reasons 2, 3 and 4
Item 6	Item 6	Changed reasons 1 and 2; added reason 5
Item 7	Item 8	Changed reasons 2 and 3
Item 8	Item 9	Changed reason 3
Item 9	Item 10	Changed reasons 2, 3 and 4
Item 10	Item 7	Changed reason 2
Item 11	Item 11	Changed four reasons
Item 12	Item 13	Changed reasons 3 and 4
Item 13	Item 3	Changed reason 4
Item 14	Item 15	Changed reasons 3 and 4, deleted reason 5
Item 15	Item 16	Deleted reason 1, changed reason 2
Item 16	Item 17	Changed reasons 1 and 3
Item 17	Item 18	Changed reasons 1, 2 and 4

The items in the final version of the diagnostic instrument and their reference to the items in the first draft are summarised in Table 7.1

Administration of Diagnostic Instrument

The first version of the two-tier diagnostic instrument consisting of 21 items was sent to two chemistry lecturers of teachers' training colleges and three chemistry teachers of school X for their comments and feedback. The feedback obtained was discussed with my supervisor. It was found that items 12, 14 and 21 produced a wide variety of reasons from the students. A decision was then made to delete Items 12, 14 and 21 and the second draft consisting of 18 items was developed.

The second version of the two-tier diagnostic instrument was sent to one lecturer, Miss K of Tun Razak Teachers' Training College, Kota Samarahan, Kuching, Malaysia for her comments and feedback. Miss K has more than ten years of experience teaching secondary school Chemistry, and is currently serving as a lecturer in a teachers college preparing chemistry major preservice teachers to teach secondary students. The feedback obtained was discussed with my supervisor and subsequently amendments were made to several items, for example, in item 3, "positively charged magnesium ions" was changed to "magnesium ions"; in item 14 since the word "oxidises" is not really emphasised in this topic, the phrase "oxidises the anode" was changed to "oxygen reacts with the carbon anode".

The final version of the instrument consisting of 17 items was administered to 330 Form Four (equivalent to Year 11) science students during the period October to November 2007. The students were from eleven classes, five classes from a government secondary school (School X), four classes from a government secondary school (School Y) and two classes from another government secondary school (School Z). The students who have been taught by teachers with at least three years of teaching experience, had completed one year of chemistry and will sit for the Malaysian Certificate Examination at the end of the following year in November 2008. Students were told before the administration of the instrument that the main emphasis was to find out their understanding of concepts relating to the electrolysis topic. The students answered the questions using specially designed answer sheets

(see Appendix H for a sample of the answer sheet). The responses from each student were then marked and feedback based on the 17 items was given back to the students through their respective teachers. A summary of the eleven Form Four classes that were involved in the administration of the diagnostic instrument is found in Table 7.2.

Table 7.2 List of Form Four classes involved in the administration of the diagnostic instrument

Date	School	Class	No. of Subjects
October 2007	School X	X1	41
October 2007	School X	X2	33
October 2007	School X	X3	39
October 2007	School X	X4	26
October 2007	School X	X5	25
October 2007	School Y	Y1	37
October 2007	School Y	Y2	40
October 2007	School Y	Y3	31
October 2007	School Y	Y4	23
November 2007	School Z	Z1	21
November 2007	School Z	Z2	14
Total number of subjects			330

Statistical Analysis of Students' Responses to the Diagnostic Instrument

The students' responses were analysed using SPSS statistics software. A summary of the analysis for the 17 items is tabulated in Table 7.3. For every content choice made by the students in the first tier of an item, the analysis provided the corresponding number who selected each of the reason choices from the second tier. The percentage of students selecting each choice combination is provided in parentheses. The most appropriate content choice and reason choice for each item are denoted with an asterisk (*). Total percentages are presented as whole numbers.

Table 7.3 Analysis of students' responses (n = 330) to the 17 items in the diagnostic instrument

Item Number	Content Choice	Reason Choice					No Reason	Total (%) ^a
		1	2	3	4	5		
1	A	10 (3.0)	20 (6.1)	*260 (78.8)	8 (2.4)	-	1 (0.3)	91
	B		22 (6.7)	9 (2.7)		-		9
2	A	36 (10.9)	*175 (53.0)	46 (13.9)	25 (7.6)	-		86
	B	16 (4.8)	18 (5.5)	7 (2.1)	7 (2.1)	-		14
3	A	27 (8.2)	13 (3.9)	30 (9.1)	26 (7.9)	-		29
	B	19 (5.8)	59 (17.9)	20 (6.1)	*136 (41.2)	-		71
4	A	49 (14.8)	*146 (44.2)	20 (6.1)	15 (4.5)	-		70
	B	20 (6.1)	32 (9.7)	23 (7.0)	25 (7.6)	-		30
5	A	15 (4.5)	19 (5.8)	27 (8.2)	77 (23.3)	-		42
	B	68 (20.6)	44 (13.3)	*64 (19.4)	16 (4.8)	-		58
6	A	28 (8.5)	17 (5.2)	33 (10.0)	*113 (34.2)	11 (3.3)		61
	B	16 (4.8)	31 (9.4)	25 (7.6)	34 (10.3)	22 (6.7)		39
7	A	17 (5.2)	22 (6.7)	*110 (33.3)	10 (3.0)	-	2 (0.6)	49
	B	37 (11.2)	46 (13.9)	19 (5.8)	67 (20.3)	-		51
8	A	43 (13.0)	23 (7.0)	17 (5.2)	42 (12.7)	-		38
	B	*125 (37.9)	34 (10.3)	19 (5.8)	27 (8.2)	-		62
9	A	36 (10.9)	36 (10.9)	63 (19.1)	*106 (32.1)	-		73
	B	19 (5.8)	26 (7.9)	21 (6.4)	23 (7.0)	-		27
10	A	22 (6.7)	90 (27.3)	25 (7.6)	18 (5.5)	-		47
	B	*82 (24.8)	36 (10.9)	21 (6.4)	36 (10.9)	-		53
11	A	44 (13.3)	45 (13.6)	28 (8.5)	13 (3.9)	-		39
	B	23 (7.0)	*145 (43.9)	20 (6.1)	12 (3.6)	-		61
12	A	24 (7.3)	28 (8.5)	43 (13.0)	*116 (35.2)	-		64
	B	11 (3.3)	21 (6.4)	37 (11.2)	50 (15.2)	-		36
13	A	33 (10.0)	*126 (38.2)	29 (8.8)	15 (4.5)	-		62
	B	12 (3.6)	26 (7.9)	47 (14.2)	42 (12.7)	-		38
14	A	53 (16.1)	*102 (30.9)	41 (12.4)	20 (6.1)	-		66
	B	35 (10.6)	33 (10.0)	30 (9.1)	16 (4.8)	-		34
15	A	30 (9.1)	60 (18.2)	*135 (40.9)	-	-		68
	B	36 (10.9)	43 (13.0)	26 (7.9)	-	-		32
16	A	51 (15.5)	19 (5.8)	*147 (44.5)	24 (7.3)	-		73
	B	18 (5.5)	39 (11.8)	13 (3.9)	19 (5.8)	-		27
17	A	33 (10.0)	23 (7.0)	30 (9.1)	*164 (49.7)	-		76
	B	14 (4.2)	31 (9.4)	16 (4.8)	19 (5.8)	-		24

a The total percentages have been reduced to the nearest one percent.

Students' overall performance in this diagnostic instrument was obtained by comparing the percentage of students who scored both parts correctly in each two-tier item with the percentage who scored only the first part correctly. The data are summarised in Table 7.4.

Table 7.4 The percentage of students who correctly answered the first part and both parts of the items in the diagnostic instrument

Item Number	Percentage of Students Who Correctly Answered		Item Number	Percentage of Students Who Correctly Answered	
	First Part	Both Parts		First Part	Both Parts
1	91	79	10	53	25
2	86	53	11	61	44
3	71	41	12	64	35
4	70	44	13	62	38
5	58	19	14	66	31
6	61	34	15	68	41
7	49	33	16	73	45
8	62	38	17	76	50
9	73	32			

The percentage of students who answered both parts of the items correctly was below 50% in 14 items, except item 1 (79%), item 2 (53%) and item 17 (50%). However, with the exception of item 1, the percentage of students who correctly answered items 2 and 17 was below the expected 75% (Gilbert, 1977).

The data indicate that the percentage of students who correctly answered the first tier of the multiple-choice items ranged from 49% to 91%. The percentage of students who correctly answered both parts of the two-tier items ranged from 19% to 79%. With the exception of Item 1, the percentage of students who correctly answered both parts of the items was less than the percentage who correctly answered the first part. This trend is an indication that students may have memorised certain facts relating to electrolysis without sufficient understanding of the concepts involved.

The difference between the two scores was relatively small (in the range 12% - 17%) for three items (Items 1, 7 and 11), while for nine items (Items 3, 4, 6, 8, 10, 12, 13, 15, 16, 17) the difference was in the range 24% - 30%. For four items (Items 2, 5, 9 and 14) the difference in scores was higher, ranging from 33% to 41%.

The overall performance of the students based on the number of students who correctly answered both tiers of each item is summarised in Table 7.5. As shown in Table 7.5, 50% of the sample obtained correct responses on both tiers from 0 to 5 items, whereas 70.3% of the sample obtained correct responses on both tiers from 0 to 8 items. The performance as a frequency distribution graph is displayed in Figure 7.1.

Table 7.5 Frequency distribution of students' scores (n = 330) for the diagnostic instrument

Score	Frequency	Percent	Cumulative Percent
0	1	0.3	0.3
1	19	5.8	6.1
2	33	10.0	16.1
3	35	10.6	26.7
4	41	12.4	39.1
5	36	10.9	50.0
6	19	5.8	55.8
7	18	5.5	61.2
8	30	9.1	70.3
9	10	3.0	73.3
10	11	3.3	76.7
11	16	4.8	81.5
12	9	2.7	84.2
13	17	5.2	89.4
14	9	2.7	92.1
15	14	4.2	96.4
16	8	2.4	98.8
17	4	1.2	100.0
Total	330	100.0	100.0

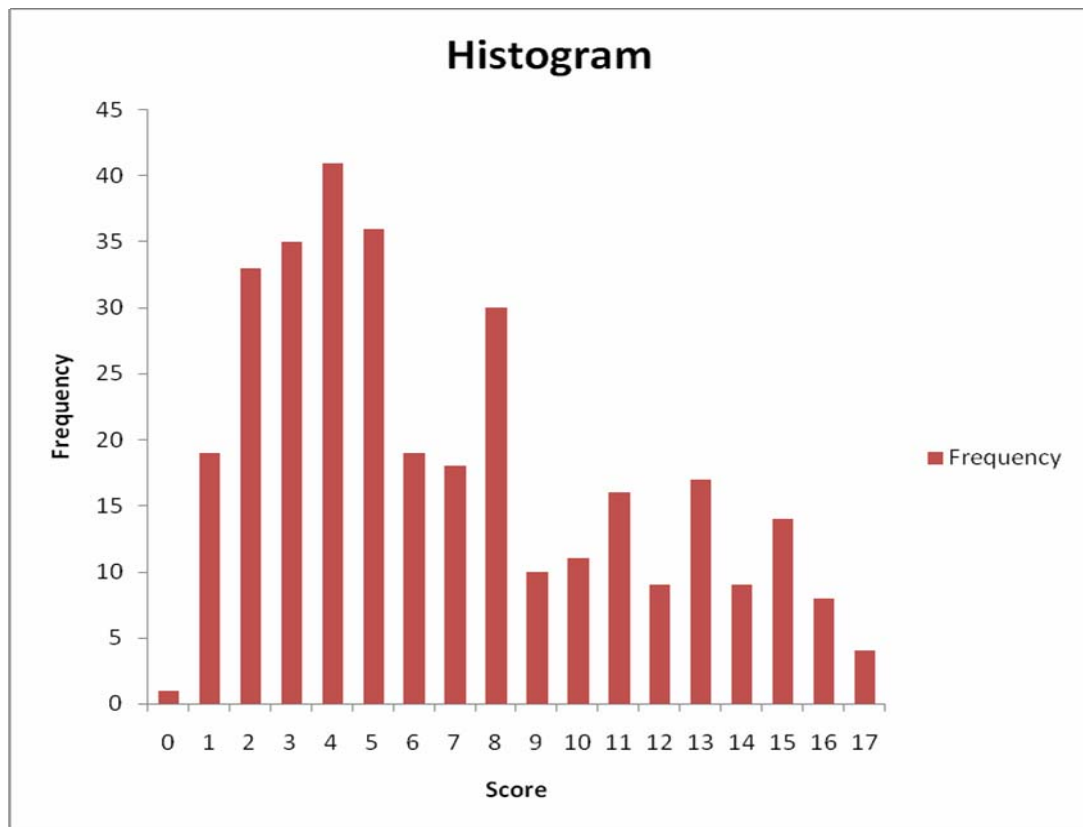


Figure 7.1 Performance as a frequency distribution graph.

Only four students obtained correct responses on both tiers in all 17 items in the diagnostic instrument, while one student was unable to answer any of the items correctly. Additional statistical data obtained by the SPSS analysis are summarised in Table 7.6.

Table 7.6 Statistical data for the diagnostic instrument

Number of cases	330
Mean	6.82
Median	5.50
Standard deviation	4.37
Variance	19.1
Minimum	0
Maximum	17

A Cronbach alpha reliability analysis performed using the SPSS software programme for the 330 cases and 17 items gave a coefficient of 0.85 which is greater than the threshold value of 0.5 quoted by Nunally and Bernstein (1994). The Cronbach alpha

coefficient, a measure of the internal consistency of the means of a set of items, is used to estimate the proportion of variance that is systematic or consistent in a set of test scores.

Table 7.7 Difficulty index and discrimination index for the 17 items in the diagnostic test

Item No.	Difficulty Index	Level of Difficulty	Discrimination Index	Type of Item
Item 1	0.79	Easy	0.42	Good
Item 2	0.53	Medium	0.67	Good
Item 3	0.41	Medium	0.65	Good
Item 4	0.44	Medium	0.71	Good
Item 5	0.19	Difficult	0.28	Satisfactory
Item 6	0.34	Difficult	0.72	Good
Item 7	0.33	Difficult	0.43	Good
Item 8	0.38	Difficult	0.72	Good
Item 9	0.32	Difficult	0.63	Good
Item 10	0.25	Difficult	0.48	Good
Item 11	0.44	Medium	0.84	Good
Item 12	0.35	Difficult	0.75	Good
Item 13	0.38	Difficult	0.72	Good
Item 14	0.31	Difficult	0.58	Good
Item 15	0.41	Medium	0.81	Good
Item 16	0.45	Medium	0.61	Good
Item 17	0.50	Medium	0.79	Good
Mean	0.40		0.64	

The values of the difficulty index and the discrimination index for each of the 17 items are summarised in Table 7.7. The difficulty index evaluates the performance on each item of the top 27% of students compared to the bottom 27% of students. (There were 89 students in each of the groups that were compared). An item with a difficulty index greater than 0.6 is considered to be easy, while an item with a difficulty index lower than 0.4 is considered to be difficult. The discrimination index compares how well an item differentiates between these top and bottom groups of low- and high-achieving students, respectively. In general, an item with a

discrimination index greater than 0.4 discriminates well between the two groups of students, while values between 0.2 and 0.4 do so satisfactorily (Lien, 1971).

Items 5, 6, 7, 8, 9, 10, 12, 13, and 14 proved to be fairly difficult and only Item 5 did not differentiate well between the top and bottom groups of students. Otherwise, the indices for the other items are acceptable.

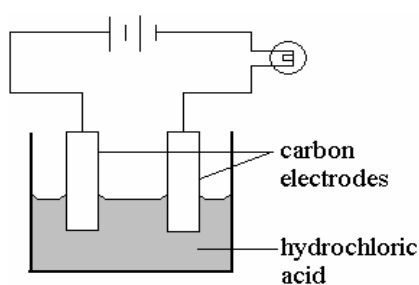
ITEM ANALYSIS OF STUDENTS' RESPONSES TO THE DIAGNOSTIC INSTRUMENT

This section deals with item analyses of the 17 items in the diagnostic instrument that was administered to the 330 Form Four students. All percentages from Table 7.5 that are quoted in the discussion of students' responses have been reduced to the nearest one percent. The correct responses in both tiers of the instrument are denoted by an asterisk (*).

Item 1:

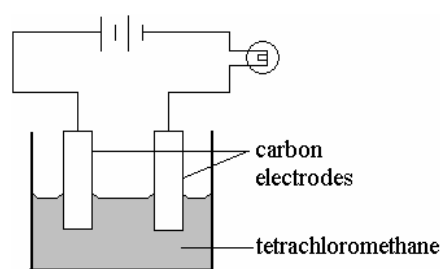
In the two experiments below we would expect the bulb to light up only in Experiment 1.

Experiment 1



- (A)* True
(B) False

Experiment 2



Reason:

- (1) Tetrachloromethane (CCl_4) contains more ions.
- (2) Tetrachloromethane (CCl_4) consists of free moving ions.
- (3)* Hydrochloric acid (HCl) consists of free moving ions.
- (4) The carbon anode dissolves producing ions.

This item assesses understanding of free moving ions in electrolytes based on the propositional knowledge statements P1, P2 and P3:

- P1 Electrolytes are substances that conduct electricity either in the molten state or in aqueous solution, and undergo chemical changes in the process.
- P2 Non-electrolytes are substances that do not conduct electricity either in the molten state or in aqueous solution.
- P3 The electrical conductivity of electrolytes is due to the presence of free moving ions in the electrolytes.

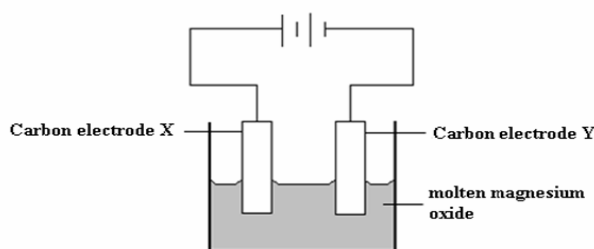
A high proportion of the students (91%) made the correct content choice (response A) that the bulb lights up due to the presence of ions. At the same time, 79% of the students in making the choice A3 responded correctly that the bulb lights up due to the presence of free moving ions in hydrochloric acid which is an electrolyte.

No alternative conception was evident among the students.

Item 1 is acceptable as it had an easy-level difficulty index of 0.79 and differentiated satisfactorily between the top and bottom comparison groups of students with a discrimination index of 0.42.

Item 2:

The diagram shows the electrolysis of molten magnesium oxide.



Electrode X is the anode.

- (A)* True
(B) False

Reason:

- (1) Positive ions move to X and accept electrons.
(2)* Negative ions move to X and donate electrons.
(3) Positive ions move to Y and donate electrons.
(4) Negative ions move to Y and accept electrons.

Item 2 assesses students' understanding of the electrode that functions as the anode, while at the same time assessing understanding of the process of electrolysis. This understanding is based on the propositional knowledge statements P7, P10, P13, P15 and P16:

P7 The electrode that is connected to the positive terminal of a battery is called the anode.

P10 Examples of inert electrodes are carbon (graphite) and platinum electrodes.

P13 Electrolytes consist of positively charged ions (cations) and negatively charged ions (anions).

P15 During electrolysis, cations (positive ions) move towards the cathode, the negatively-charged electrode whereas anions (negative ions) move towards the anode, the positively-charged electrode.

- P16 Cations are discharged at the cathode by accepting electron(s) from the cathode, whereas anions are discharged at the anode by donating electron(s) to the anode.

A large proportion of the students (86%) made the correct content choice (response A), displaying understanding that during electrolysis the anode is connected to the positive terminal of the battery. Yet, only 53% of the students in selecting A2, displayed understanding that during electrolysis negative ions migrate to the anode and donate electrons.

Fourteen percent of the students who made content choice B held the alternative conception that during electrolysis the cathode is connected to the positive terminal of the battery. In a similar finding by Garnett and Treagust (1992b) students suggested that “in an electrolytic cell the polarity of the applied voltage has no effect on the site of the anode and cathode” (p. 1092). An alternative conception was held by 11% of the students in making the selection A1 showing the belief that during electrolysis the cations migrate to the anode, thus considering the anode as a source of electrons for the cations. In selecting A3, 14% of the students displayed the alternative conception that cations (positive ions) possess an excess of electrons.

Item 2 is acceptable as it had a medium-level difficulty index of 0.53 and differentiated satisfactorily between the top and bottom comparison groups of students with a discrimination index of 0.67.

Item 3:

In the electrolysis of molten magnesium oxide using carbon electrodes, magnesium is produced at the anode.

- (A) True
(B)* False

Reason:

- (1) Magnesium ions are attracted to the anode and accept electrons.
- (2) Magnesium ions are attracted to the cathode and donate electrons.
- (3) Magnesium ions are attracted to the anode and donate electrons.
- (4)* Magnesium ions are attracted to the cathode and accept electrons.

Item 3 assesses students' understanding of the electrode at which magnesium will be produced. It also assesses understanding of what happens to the magnesium ions in terms of electron transfer to form magnesium metal. This understanding is based on the propositional knowledge statements P13, P15, P16 and P17:

- P13 Electrolytes consist of positively charged ions (cations) and negatively charged ions (anions).
- P15 During electrolysis, cations (positive ions) move towards the cathode, the negatively-charged electrode whereas anions (negative ions) move towards the anode, the positively-charged electrode.
- P16 Cations are discharged at the cathode by accepting electron(s) from the cathode, whereas anions are discharged at the anode by donating electron(s) to the anode.
- P17 In the electrolysis of molten magnesium oxide using carbon electrodes, magnesium is produced at the cathode and oxygen at the anode.

A large proportion of the students (71%) made the correct content choice (response B) that magnesium is not produced at the anode. Yet, only 41% of the students correctly suggested that magnesium ions are attracted to the cathode and accept electrons (reason 4).

Twenty-nine percent of the students who made content choice A held the alternative conception that magnesium is produced at the anode during electrolysis of molten magnesium oxide. In their attempt to explain the chemical reaction, 18% of the students who had selected B2 displayed the alternative conception that magnesium ions are attracted to the cathode where excess electrons on the cations are given up.

Item 3 is acceptable as it had a medium-level difficulty index of 0.41 and differentiated satisfactorily between the top and bottom comparison groups of students with a discrimination index of 0.65.

Item 4:

During electrolysis of molten lead(II) bromide using graphite electrodes, reddish fumes of bromine gas and molten lead are produced.

- (A)* True
- (B) False

Reason:

- (1) Bromide ions move to the cathode and are oxidised.
- (2)* Bromide ions donate electrons at the anode and form bromine molecules.
- (3) Lead(II) ions are positively charged and so move to the anode.
- (4) Oxygen is attracted to the anode.

Item 4 assesses the students' understanding of the products produced at the cathode and the anode. This item also tests the students' understanding of oxidation and reduction in terms of donating and losing electrons. This understanding is based on the propositional statements P13, P15, P16, P18 and P19:

P13 During electrolysis, cations (positive ions) move towards the cathode, the negatively-charged electrode whereas anions (negative ions) move towards the anode, the positively-charged electrode.

P15 During electrolysis, cations (positive ions) move towards the cathode, the negatively-charged electrode whereas anions (negative ions) move towards the anode, the positively-charged electrode.

P16 Cations are discharged at the cathode by accepting electron(s) from the cathode, whereas anions are discharged at the anode by donating electron(s) to the anode.

P18 In the electrolysis of molten lead(II) bromide using graphite electrodes, lead is produced at the cathode and bromine gas at the anode.

P19 Reduction occurs at the cathode and oxidation occurs at the anode during electrolysis.

Seventy percent of the students in making the correct content choice (response A) agreed that the products of bromine gas and lead are produced. By making the selection A2, 44% of the students agreed that bromide ions donate electrons at the anode to form bromine molecules. This supports Schmidt et al.'s (2007) improved definition of "The electrode at which oxidation occurs is called the anode: Particles (could be atoms or ions) lose electrons to the electrode" (p. 260).

Fifteen percent of the students who selected A1 held the alternative conception that bromide ions migrate to the cathode and are oxidised, similar to a finding by Garnett and Treagust (1992b) that oxidation occurs at the cathode in electrolytic cells.

Item 4 is acceptable as it had a medium-level difficulty index of 0.44 and differentiated well between the top and bottom comparison groups of students with a discrimination index of 0.71.

Item 5:

When dilute aqueous iron(II) sulphate solution is electrolysed using platinum electrodes, the light green colour of the solution becomes fainter.

- (A) True
- (B)* False

Reason:

- (1) Neither iron(II) ions nor sulphate ions are discharged, so the concentration of the solution remains unchanged.
- (2) Hydrogen ions and hydroxide ions are discharged, so the concentration of the solution remains unchanged.
- (3)* Hydrogen ions and hydroxide ions are discharged, so the concentration of the solution increases.
- (4) The concentration of iron(II) ions decreases as iron is deposited at the cathode.

Item 5 assesses the students' understanding of the electrolysis of aqueous solutions using inert electrodes. It also assesses the students' application of the electrochemical series to decide which ion will be preferably discharged. This understanding is based on the propositional statements P21, P22, P23, P24 and P25:

- P21 An aqueous solution of a compound contains anions and cations of the compound, hydrogen ions, and hydroxide ions from the partial dissociation of water molecules.
- P22 During electrolysis of an aqueous solution of a compound, two different types of cations move towards the cathode, which are cations of the compound and hydrogen ions.
- P23 During electrolysis of an aqueous solution of a compound, two different types of anions move towards the anode, which are anions of the compound and hydroxide ions.
- P24 The selective discharge of ions depends on the positions of ions in the electrochemical series, the concentration of ions in the electrolyte, and the nature of electrodes used in the electrolysis.
- P25 The electrochemical series is a list of ions arranged in order of their tendency to be discharged during electrolysis. The lower the position of an ion in the electrochemical series, the higher is the tendency for the ion to be discharged.

Fifty-eight percent of the students in making the correct content choice (response B) agreed that the light green colour does not become fainter. However, an even smaller proportion of the students (19%) who made the correct selection B3 reasoned that hydrogen ions and hydroxide ions are discharged.

Several alternative conceptions were evident from students' responses to this item. By selecting A4, 23% of the students attributed the decrease in the intensity of the colour of the solution to a decrease in the concentration of iron(II) ions as iron is deposited at the cathode. These students displayed the alternative conception that during electrolysis of aqueous iron (II) sulphate using inert electrodes, iron(II) ions are selectively discharged over hydrogen ions. Probably due to lack of understanding of the electrochemical series, they were not able to decide that hydrogen ions should be preferably discharged over iron(II) ions. This alternative conception may also be attributed to students learning by rote about the electrolysis of aqueous copper(II)

sulphate as explained in their textbook (Loh & Tan, 2006, p. 169) and incorrectly transferring their knowledge to the electrolysis of aqueous iron(II) sulphate.

Thirteen percent of the students in choosing B2 suggested that the colour of the solution remained unchanged due to hydrogen ions and hydroxide ions being discharged. This group of students in displaying the correct application of the electrochemical series failed to predict the consequence of the discharge of hydrogen and hydroxide ions on the concentration of the electrolyte. By selecting B1, 21% of the students suggested that neither iron(II) ions nor sulphate ions are discharged, so the concentration of the solution remains unchanged. The option B1 is not considered as an alternative conception as this group of students showed understanding of the application of the electrochemical series to decide which ion will be preferably discharged.

Item 5 is considered to be a difficult item as it had a difficulty index of 0.19 and differentiated poorly between the top and bottom comparison groups of students with a discrimination index of 0.28.

Item 6:

The products of electrolysis of dilute sulphuric acid using inert electrodes are hydrogen at the cathode and oxygen at the anode.

- (A)* True
- (B) False

Reason:

- (1) Sulphate and hydrogen ions are selectively discharged.
- (2) Sulphate and hydroxide ions are selectively discharged.
- (3) The electrolyte consists of hydrogen ions and oxygen ions.
- (4)* Hydrogen and hydroxide ions are selectively discharged.
- (5) No reaction occurs because platinum electrodes are inert.

Item 6 assesses students' understanding of the products formed at the electrodes during electrolysis of aqueous solution using inert electrodes. This requires

understanding of the electrochemical series. This item is based on the propositional statements P22, P23, P24, P25 and P26:

- P22 During electrolysis of an aqueous solution of a compound, two different types of cations move towards the cathode, which are cations of the compound and hydrogen ions.
- P23 During electrolysis of an aqueous solution of a compound, two different types of anions move towards the anode, which are anions of the compound and hydroxide ions.
- P24 The selective discharge of ions depends on the positions of ions in the electrochemical series, the concentration of ions in the electrolyte, and the nature of electrodes used in the electrolysis.
- P25 The electrochemical series is a list of ions arranged in order of their tendency to be discharged during electrolysis. The lower the position of an ion in the electrochemical series, the higher is the tendency for the ion to be discharged.
- P26 Electrolysis of dilute sulphuric acid using inert carbon electrodes will produce hydrogen gas at the cathode, and oxygen gas at the anode.

A relatively high proportion of the students (61%) made the correct content choice (response A) that hydrogen is produced at the cathode and oxygen at the anode. However, only 34% of the students in making the choice A4 responded correctly that hydrogen and hydroxide ions are selectively discharged. These students (34%) displayed the ability of listing all the ions present during electrolysis and are able to apply the electrochemical series in selecting the ions being discharged.

In choosing A3, an alternative conception was evident among 10% of the students that during the electrolysis of dilute sulphuric acid using inert electrodes, oxygen produced at the anode was from the oxygen ions in the electrolyte. This group of students showed lack of understanding with regard to the ions present in an aqueous solution. Another 10% of the students in choosing B4 held the alternative conception

that hydrogen is produced at the anode and oxygen at the cathode. This implied that the students could have made the assumption that the cations (positively-charged ions) migrated to the anode which is negatively charged as in a galvanic cell (Garnett & Treagust, 1992b).

Item 6 is acceptable as it had a difficulty index of 0.34 and differentiated well between the top and bottom comparison groups of students with a discrimination index of 0.72.

Item 7:

When dilute sulphuric acid is electrolysed using inert electrodes, the concentration of the electrolyte increases.

- (A)* True
- (B) False.

Reason:

- (1) Hydrogen and oxide ions are selectively discharged, so the concentration of the acid decreases.
- (2) Hydrogen and sulphate ions are selectively discharged, so the concentration of the acid decreases.
- (3)* Hydrogen and hydroxide ions are selectively discharged, so the concentration of the acid increases.
- (4) Hydrogen and hydroxide ions are selectively discharged, so the concentration of the acid remains the same.

Item 7 is assessing students' understanding of the changes to the concentration of the electrolyte. This is based on the propositional statements P25, P26 and P27:

P25 The electrochemical series is a list of ions arranged in order of their tendency to be discharged during electrolysis. The lower the position of an ion in the electrochemical series, the higher is the tendency for the ion to be discharged.

P26 Electrolysis of dilute sulphuric acid using inert carbon electrodes will produce hydrogen gas at the cathode, and oxygen gas at the anode.

P27 The concentration of sulphuric acid increases gradually as water is decomposed to hydrogen gas and oxygen gas.

Only 49% of the students made the correct content choice by selecting response A that the concentration of the electrolyte increases. However, an even smaller proportion of students (33%) who made the correct selection A3 agreed with the explanation that hydrogen and hydroxide ions are selectively discharged.

Several alternative conceptions were evident for this item. Sixteen percent of the students who selected B1 believed that hydrogen and oxide ions were selectively discharged, so the concentration of the acid decreased. This group of students displayed lack of understanding about the types of ions present in an aqueous solution. Similarly, 21% of the students who selected B2 suggested that hydrogen and sulphate ions were selectively discharged, again showing lack of understanding about the types of ions present in an aqueous solution. Another 23% of the students who selected B4 suggested that hydrogen and hydroxide ions are selectively discharged, so the concentration of the acid remains the same. This group of students showed the correct application of the electrochemical series; however they could not further explain that the decrease of hydrogen ions and hydroxide ions in the solution resulted in an increase in the concentration of the electrolyte (Loh & Tan, 2006).

Item 7 is acceptable as it had a difficulty index of 0.33 and differentiated satisfactorily between the top and bottom comparison groups of students with a discrimination index of 0.43.

Item 8:

When aqueous copper(II) sulphate solution is electrolysed using platinum electrodes, a reddish-brown deposit is produced at the cathode. At the same time, the blue colour of the electrolyte remains unchanged.

- (A) True
- (B)* False

Reason:

- (1)* Copper(II) ions are discharged and deposited at the cathode, so the colour of the electrolyte decreases in intensity.
- (2) Copper(II) ions are displaced by platinum, so the colour of the electrolyte decreases in intensity.
- (3) Platinum dissolves in the electrolyte, so the colour of the electrolyte increases in intensity.
- (4) Platinum electrodes are inert, so the colour of the electrolyte remains the same.

Item 8 assesses understanding of the product formed at the cathode and the change in colour of the electrolyte during electrolysis. This understanding is based on the propositional knowledge statements P28, P29, P30 and P32:

- P28 Electrolysis of aqueous copper(II) sulphate using inert carbon electrodes will produce copper at the cathode, and oxygen gas at the anode.
- P29 The aqueous solution of copper (II) sulphate consists of copper(II) ions, sulphate ions, hydrogen ions, and hydroxide ions that move freely.
- P30 During electrolysis of aqueous solution of copper(II) sulphate, the copper(II) and hydrogen ions move to the cathode. Copper(II) ions are selectively discharged to form copper metal.
- P32 The intensity of the blue colour of the electrolyte decreases as the concentration of blue copper(II) ions decreases when more copper is deposited on the cathode.

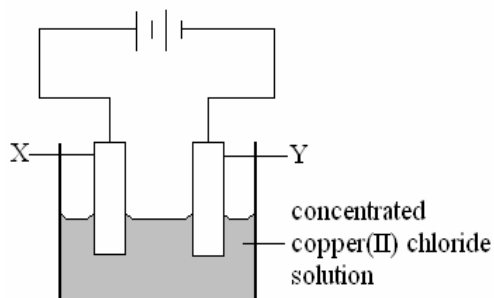
A relatively high proportion of the students (62%) made the correct content choice (response B) that it is not true that the blue colour of the electrolyte remains unchanged. At the same time, only 38% of the students in making the choice B1 responded correctly that copper(II) ions are discharged and deposited at the cathode, so the colour of the electrolyte decreases in intensity.

The combination A1 (although selected by 13% of students) was not considered as alternative conception because the reason 1 where the colour of the electrolyte decreases in intensity does not make sense to explain the content choice where the electrolyte remains unchanged. Two alternative conceptions were evident for this item. Ten percent of the students in choosing B2 believed that copper(II) ions were displaced by platinum, resulting in the colour of the electrolyte to decrease in intensity. This group of students displayed the lack of understanding in the role of platinum as an inert electrode. Another alternative conception held by 13% of the students (in selecting A4) suggested that the colour of the electrolyte remains unchanged due to the inert platinum electrodes similar to the alternative conception that no reaction occurs at the surfaces of inert electrodes identified in a previous study (Garnett & Treagust, 1992b). This was also reported in Sanger and Greenbowe (1997a) that “no reaction will occur if inert electrodes are used” (p.390) while Schmidt et al. (2007) also reported that “students did not consider the transfer of electrons at the electrode” (p. 265).

Item 8 is acceptable as it had a difficulty index of 0.38 and differentiated well between the top and bottom comparison groups of students with a discrimination index of 0.72.

Item 9:

The diagram below shows an electrolytic cell in which an electric current passes through a concentrated aqueous solution of copper(II) chloride using inert graphite electrodes.



At electrode X, chloride ions are oxidised.

- (A)* True
- (B) False

Reason:

- (1) Copper(II) ions move to X and accept electrons.
- (2) Copper(II) ions move to X and donate electrons.
- (3) Chloride ions move to X and accept electrons.
- (4)* Chloride ions move to X and donate electrons.

Item 9 assesses understanding of the ions preferably discharged using inert electrodes. It also assesses the understanding of oxidation in terms of electron transfer. This is based on the propositional knowledge statements P7, P19, P23, P24 and P25:

P7 The electrode that is connected to the positive terminal of a battery is called the anode.

P19 Reduction occurs at the cathode and oxidation occurs at the anode during electrolysis.

- P23 During electrolysis of an aqueous solution of a compound, two different types of anions move towards the anode, which are anions of the compound and hydroxide ions.
- P24 The selective discharge of ions depends on the positions of ions in the electrochemical series, the concentration of ions in the electrolyte, and the nature of electrodes used in the electrolysis.
- P25 The electrochemical series is a list of ions arranged in order of their tendency to be discharged during electrolysis. The lower the position of an ion in the electrochemical series, the higher is the tendency for the ion to be discharged.

A high proportion of the students (73%) made the correct content choice (response A) that chloride ions are oxidised at the anode. Only 32% of the students in making the choice A4 are correct in explaining that chloride ions migrate to the anode and donate electrons.

Twenty-two percent of the students (in selecting A1 and A2) held the alternative conception that copper(II) ions migrate to the anode. These students could have made the assumption that the cations (positively-charged ions) migrate to the anode which is negatively charged as in a galvanic cell (Garnett & Treagust, 1992b). Another 19% of the students in making the choice A3 displayed the alternative conception that anions migrate to the anode and accept electrons, implying that reduction has occurred at the anode as in an electrolytic cell (Garnett & Treagust, 1992b). Students could have regarded “anodes, like anions, are always negatively charged” (Sanger & Greenbowe, 1997a, p. 384).

Item 9 is acceptable as it had a difficulty index of 0.32 and differentiated satisfactorily between the top and bottom comparison groups of students with a discrimination index of 0.63.

Item 10:

When dilute aqueous zinc nitrate solution is electrolysed using graphite electrodes, bubbles of gas are given off only at the cathode.

- (A) True
(B)* False

Reason:

- (1)* Hydrogen and hydroxide ions are selectively discharged over zinc and nitrate ions.
(2) Hydrogen ions are discharged at the cathode, producing hydrogen gas.
(3) Reaction occurs between zinc ions and the graphite electrodes.
(4) Zinc is deposited at the cathode.

Item 10 assesses students' understanding of the products formed during electrolysis using graphite electrodes. This is based on the propositional knowledge statements P23, P24 and P25:

P23 During electrolysis of an aqueous solution of a compound, two different types of anions move towards the anode, which are anions of the compound and hydroxide ions.

P24 The selective discharge of ions depends on the positions of ions in the electrochemical series, the concentration of ions in the electrolyte, and the nature of electrodes used in the electrolysis.

P25 The electrochemical series is a list of ions arranged in order of their tendency to be discharged during electrolysis. The lower the position of an ion in the electrochemical series, the higher is the tendency for the ion to be discharged.

Only 25% of the students (who had made the selection B1) displayed the ability to explain that bubbles of gas are given off not only at the cathode, but also at the anode because hydrogen and hydroxide ions are selectively discharged over zinc and nitrate ions. A higher proportion of students (53%) made the correct content choice (response B) indicating a better understanding only at macroscopic level where bubbles of gas are given off. This supports Nakhleh et al.'s (2005) finding that

middle school students have difficulty of assimilating the sub microscopic level scientific knowledge acquired through formal instruction.

Twenty-seven percent of the students (in selecting A2) held the alternative conception that hydrogen is the gas given off at the cathode and no other gas is given off at the anode. In choosing B2, 11% of the students held the alternative conception that hydrogen gas is produced at the cathode and it is the only gas produced during electrolysis. Another 11% of the students (in selecting B4) held the alternative conception that zinc is deposited at the cathode, confusing this process with electroplating.

Item 10 is acceptable as it had a difficulty index of 0.25 and differentiated satisfactorily between the top and bottom comparison groups of students with a discrimination index of 0.48.

Item 11:

In order to electroplate an iron spoon with silver using aqueous silver nitrate solution as electrolyte, the spoon should be used as the anode.

- (A) True
- (B)* False

Reason:

- (1) Silver ions are attracted to the anode and selectively discharged.
- (2)* Silver ions are attracted to the cathode and selectively discharged.
- (3) Hydrogen ions are attracted to the cathode and selectively discharged.
- (4) Hydrogen ions are attracted to the anode and selectively discharged.

Item 11 is similar to Item 12 testing electroplating. This item assesses students' understanding of the action of active electrodes in electrolysis. This understanding is based on the propositional knowledge statements P12, P37 and P39:

P12 Examples of active electrodes are metal electrodes such as copper and silver.

P37 Electroplating is the process of depositing a layer of metal on another substance using electrolysis.

P39 To electroplate an object with a metal, the cathode is the object to be plated, the anode is a piece of the pure plating metal and the electrolyte shall contain ions of the plating metal.

A relatively high proportion of the students (61%) made the correct content choice (response B) agreeing that the spoon should not be used as the anode. At the same time, 44% of the students in choosing B2 agreed that silver ions are attracted to the cathode and selectively discharged.

Thirty-nine percent of the students held the alternative conception that the spoon should be used as the anode (response A), with 13% of the students in choosing A1 explaining that silver ions are attracted to the anode and selectively discharged. This group of students choosing A1 held the alternative conception that cations migrate to the anode. These students could have made the assumption that the cations (positively-charged ions) migrate to the anode which is negatively charged as in a galvanic cell (Garnett & Treagust, 1992b). Sanger and Greenbowe (1997a) suggested the computer animation of the electrolytic cell illustrating the plating of silver metal on an iron spoon could help to reduce the number of students holding the misconceptions. Another 14% of the students in selecting A2 explained that silver ions are attracted to the cathode and selectively discharged. Option A2 chosen by 14% of the students is not considered an alternative conception because this option does not make sense.

Item 11 is acceptable as it had a medium-level difficulty index of 0.44 and differentiated well between the top and bottom comparison groups of students with a discrimination index of 0.84.

Item 12:

In order to purify an impure copper plate using aqueous copper(II) sulphate solution, a pure copper plate must be used as the cathode.

- (A)* True
- (B) False

Reason:

- (1) Hydrogen ions are attracted to the cathode and selectively discharged.
- (2) Hydrogen ions are attracted to the anode and selectively discharged.
- (3) Copper(II) ions are attracted to the anode and selectively discharged.
- (4)* Copper(II) ions are attracted to the cathode and selectively discharged.

Item 12 assesses students' understanding on purification of metals using electrolysis. This item also requires the understanding of the types of ions present and the movement of the ions to the respective electrodes. This is based on the propositional knowledge statements P12, P22, P23, P24 and P36:

- P12 Examples of active electrodes are metal electrodes such as copper and silver.
- P22 During electrolysis of an aqueous solution of a compound, two different types of cations move towards the cathode, which are cations of the compound and hydrogen ions.
- P23 During electrolysis of an aqueous solution of a compound, two different types of anions move towards the anode, which are anions of the compound and hydroxide ions.
- P24 The selective discharge of ions depends on the positions of ions in the electrochemical series, the concentration of ions in the electrolyte, and the nature of electrodes used in the electrolysis.
- P36 In the purification of metals using electrolysis, the impure metal is the anode, the pure metal is the cathode, and the electrolyte is an aqueous salt solution of the metal.

A relatively high proportion of the students (64%) made the correct content choice (response A) that a pure copper plate must be used as the cathode. By making the selection A4, only 35% of the students made the correct explanation that copper(II) ions are attracted to the cathode and selectively discharged.

The main alternative conception from this item was held by 11% of the students, who in selecting B3, implied that copper(II) ions are attracted to the anode and are selectively discharged. These students could have made the assumption that the cations (positively-charged ions) move to the anode which is negatively charged as in a galvanic cell (Garnett & Treagust, 1992b). Options A3, B4 chosen by 13%, 15% of the students, respectively, are not considered as alternative conceptions as the reason made no sense in explaining the option.

Item 12 is acceptable as it had a difficulty index of 0.35 and differentiated well between the top and bottom comparison groups of students with a discrimination index of 0.75.

Item 13:

In the manufacture of chlorine by electrolysis of concentrated aqueous sodium chloride solution using graphite electrodes, hydrogen gas is also produced.

- (A)* True
- (B) False

Reason:

- (1) Hydrogen ions are preferably discharged over hydroxide ions.
- (2)* Hydrogen ions are selectively discharged over sodium ions.
- (3) Aqueous sodium chloride does not contain hydrogen ions.
- (4) The concentration of hydrogen ions is very low.

Item 13 assesses students' understanding on the ions selectively discharged and the products formed during electrolysis in industry. This is based on the propositional knowledge statements P22, P23 and P24:

- P22 During electrolysis of an aqueous solution of a compound, two different types of cations move towards the cathode, which are cations of the compound and hydrogen ions.
- P23 During electrolysis of an aqueous solution of a compound, two different types of anions move towards the anode, which are anions of the compound and hydroxide ions.
- P24 The selective discharge of ions depends on the positions of ions in the electrochemical series, the concentration of ions in the electrolyte, and the nature of electrodes used in the electrolysis.

A relatively high proportion of the students (62%) made the correct content choice (response A) that hydrogen gas is also produced in the manufacture of chlorine by electrolysis of concentrated aqueous sodium chloride using graphite electrodes. By making the selection A2, only 38% of the students made the correct explanation that hydrogen ions are selectively discharged over sodium ions.

Several alternative conceptions were evident for this item. In selecting A1, 10% of the students held the alternative conception that hydrogen ions are preferably discharged over hydroxide ions, displaying a lack of understanding about the migration of cations and anions to the correct electrode. Fourteen percent of the students who had selected B3 held the alternative conception that a concentrated aqueous solution does not contain hydrogen ions, which is to say water does not react during electrolysis of aqueous solutions (Garnett & Treagust, 1992b). Another 13% of the students who had selected B4 held the alternative conception that the concentration of hydrogen ions is very low. This group of students who displayed understanding of the low concentration of hydrogen ions in a concentrated solution, however, lacked understanding of the three factors that influence the selective discharge of ions.

Item 13 is acceptable as it had a difficulty index of 0.38 and differentiated well between the top and bottom comparison groups of students with a discrimination index of 0.72.

Item 14:

In the extraction of aluminium by the electrolysis of molten aluminium oxide using graphite electrodes, the graphite anode has to be periodically replaced.

- (A)* True
- (B) False

Reason:

- (1) The anode dissolves in the hot molten aluminium oxide.
- (2)* The oxygen produced at high temperatures reacts with the anode.
- (3) The cathode dissolves in the hot molten aluminium oxide.
- (4) The oxygen produced at high temperatures reacts with the cathode.

Item 14 assesses students' understanding on the extraction of metal ores in industry. This is based on the propositional knowledge statements P10, P15, P16 and P35:

P10 Examples of inert electrodes are carbon (graphite) and platinum electrodes.

P15 During electrolysis, cations (positive ions) move towards the cathode, the negatively-charged electrode whereas anions (negative ions) move towards the anode, the positively-charged electrode.

P16 Cations are discharged at the cathode by accepting electron(s) from the cathode, whereas anions are discharged at the anode by donating electron(s) to the anode.

P35 Highly reactive metals can only be extracted from their ores by electrolysis.

Although 66% of the students made the correct content choice (response A) only 31% of the students were able to relate that the oxygen produced at high temperatures reacts with the anode by making the selection A2.

In selecting A1, 16% of the students held the alternative conception that the anode dissolves in the hot molten aluminium oxide but did not relate to the oxygen

produced. This shows that the students had difficulty in linking the action of the product produced at the anode. Option A3 selected by 12% of the students is not considered as an alternative conception as the option does not make sense. In choosing B1 and B2, 21% of the students held the alternative conception that the graphite anode does not have to be periodically replaced.

Item 14 is acceptable as it had a difficulty index of 0.31 and differentiated satisfactorily between the top and bottom comparison groups of students with a discrimination index of 0.58.

Item 15:

The use of electrolysis in industry causes pollution of the environment.

- (A)* True
- (B) False

Reason:

- (1) Gases such as hydrogen and oxygen are released into the atmosphere.
- (2) Chemical wastes are released into the environment after proper treatment.
- (3)* Heavy metal ions such as cadmium and nickel ions are released into water sources.

Item 15 assesses students' understanding on the impact of electrolysis on the environment. This is based on the propositional knowledge statements P41:

- P41 The industrial use of electrolysis may cause pollution as a result of the production of waste chemicals from the electroplating industry that are released into the environment.

A relatively high proportion of the students (68%) made the correct content choice (response A) that the use of electrolysis in industry causes pollution of the environment. Nevertheless, only 41% of the students in making the selection A3 displayed an understanding that heavy metal ions such as cadmium and nickel ions are released into water resources.

In selecting reason A2, 18% of the students displayed the alternative conception that chemical wastes are released into the environment after proper treatment. In selecting content choice B, 32% of the students displayed the alternative conception that the use of electrolysis does not cause pollution of the environment. Both these alternative conceptions suggest that students are rather ignorant of environmental issues, supporting the view held by Gilbert, Treagust and Gobert (2003) that environmental education has become steadily more significant and should be given due attention. Dillon (2002) has also reported that environmental education “provides an opportunity to bring in modern and challenging social and scientific issues into the classroom that is currently hindered by the packed and conservative science curricula of many countries around the world” (p. 1112).

Item 15 is acceptable as it had a medium-level difficulty index of 0.41 and differentiated well between the top and bottom comparison groups of students with a discrimination index of 0.81.

Items 16 and 17 are two examples in which electrolysis is used in industry for electroplating.

Item 16:

In the motor industry, the metals nickel and chromium are used for electroplating.

- (A)* True
- (B) False

Reason:

- (1) The metals have high boiling and melting points.
- (2) The metals do not form a strongly adhering coating.
- (3)* The metals prevent rusting.
- (4) The metals are chemically unreactive.

Item 16 is assessing students' understanding on electroplating used in the motor industry. This is based on the propositional knowledge statements P38:

- P38 Objects are electroplated to protect them from corrosion and to give them an attractive appearance.

Seventy-three percent of the students in making the correct content choice (response A) agreed that the metals nickel and chromium are used for electroplating in the motor industry. By making the selection A3, 45% of the students agreed with the explanation that the metals prevent rusting.

In selecting B2, 12% of the students held the alternative conception that the metals nickel and chromium do not form a strongly adhering coating. Sixteen percent of the students who selected A1 explained that the metals nickel and chromium have high melting points. This is not considered as an alternative conception as an explanation; although it is a correct statement of fact, the reason is not relevant to the answer in the first tier.

Item 16 is acceptable as it had a medium-level difficulty index of 0.45 and differentiated satisfactorily between the top and bottom comparison groups of students with a discrimination index of 0.61.

Item 17:

Cutlery items are often electroplated with silver and nickel.

- (A)* True
- (B) False

Reason:

- (1) Nickel reacts readily with silver.
- (2) Silver and nickel are expensive metals.
- (3) The cutlery becomes more brittle.
- (4)* The cutlery becomes more resistant to corrosion.

Item 17 is assessing students' understanding on the use of electroplating on cutlery items. This is based on the propositional knowledge statement:

- P38 Objects are electroplated to protect them from corrosion and to give them an attractive appearance.

A high proportion of the students (76%) who made the correct content choice (response A) agreed that the cutlery items are often electroplated with silver and nickel. By making the selection A4, 50% of the students agreed with the explanation that the cutlery items with electroplating become more resistant to corrosion.

There is only one alternative conception held by 10% of the students who selected A1 explaining that nickel reacts readily with silver, making it suitable for electroplating cutlery items.

Item 17 is acceptable as it had a medium-level difficulty index of 0.50 and differentiated well between the top and bottom comparison groups of students with a discrimination index of 0.79.

SUMMARY OF ALTERNATIVE CONCEPTIONS HELD BY STUDENTS

The item analysis of the 17 items that was reported in the preceding section has revealed that 29 alternative conceptions were held by the Form 4 students to whom the instrument was administered. These alternative conceptions were identified using the criteria that 10% or more of the students had chosen the answer as shown in Table 7.3. These 29 alternative conceptions, which relate to the students' ability to explain electrolysis are summarised in Table 7.8. Some of the alternative conceptions were revealed in more than one item. These repeating alternative conceptions are listed only the first time they have been identified. No alternative conceptions were evident from Item 1.

Table 7.8 Alternative conceptions held by students (n = 330) about items in electrolysis diagnostic instrument

Electrolysis Reactions	Item No.	Choice	Alternative Conceptions
Electrolyte and non-electrolyte	1	None	
Electrodes: Anode and cathode	2	B	AC1: The terminal connected to the positive terminal of the battery is the cathode. (14%)
		A1	AC2: During electrolysis the cations migrate to the anode. (11%)
		A3	AC3: Cations (positive ions) possess an excess of electrons. (14%)
Electrolysis of molten magnesium oxide using carbon electrodes	3	B2	AC4: During electrolysis of molten magnesium oxide using inert electrodes magnesium ions are attracted to the cathode where excess electrons on the cations are given up. (18%)
Electrolysis of molten lead(II) bromide using graphite electrodes	4	A1	AC5: During electrolysis of molten lead(II) bromide using inert electrodes bromide ions are oxidised at the cathode. (15%)
Electrolysis of dilute aqueous iron(II) sulphate solution using platinum electrodes	5	A4	AC6: During electrolysis of dilute aqueous iron(II) sulphate solution using inert electrodes iron(II) ions are selectively discharged over hydrogen ions. (23%)
		B1	Non C: During electrolysis of dilute aqueous iron(II) sulphate solution using inert electrodes neither iron(II) ions nor sulphate ions are discharged. (21%)
		B2	AC7: During electrolysis of dilute aqueous iron(II) sulphate solution using inert electrodes the concentration of the solution remains unchanged. (13%)
Electrolysis of dilute sulphuric acid using inert electrodes	6	A3	AC8: During electrolysis of dilute sulphuric acid using inert electrodes, oxygen is produced at the anode as a result of the discharge of oxygen ions. (10%)
		B4	AC9: During electrolysis of dilute sulphuric acid using inert electrodes, the products are oxygen at the cathode and hydrogen at the anode. (10%)

Electrolysis Reactions	Item No.	Choice	Alternative Conceptions
	7	B1	AC10: During electrolysis of dilute sulphuric acid using inert electrodes, the concentration of the solution decreases because hydrogen and oxygen ions are selectively discharged. (11%)
		B2	AC11: During electrolysis of dilute sulphuric acid using inert electrodes, the concentration of the solution decreases because hydrogen and sulphate ions are selectively discharged. (14%)
		B4	AC12: During electrolysis of dilute sulphuric acid using inert electrodes, the concentration of the solution remains unchanged. (20%)
Electrolysis of aqueous copper(II) sulphate using platinum electrodes	8	A4	AC13: During electrolysis of aqueous copper (II) sulphate using platinum electrodes, platinum does not take part in the reaction. (13%)
		B2	AC14: During electrolysis of aqueous copper(II) sulphate using platinum electrodes, copper ions are displaced by platinum. (10%)
Electrolysis of concentrated aqueous solution of copper(II) chloride using graphite electrodes	9	A1& A2	AC15: During electrolysis of concentrated aqueous solution of copper(II) chloride using graphite electrodes, cations migrate to the anode. (22%)
		A3	AC16: During electrolysis of concentrated aqueous solution of copper(II) chloride using graphite electrodes, anions migrate to the anode and accept electrons. (19%)
Electrolysis of dilute aqueous zinc nitrate solution using graphite electrodes	10	A2 & B2	Non C: When dilute aqueous zinc nitrate solution is electrolysed using graphite electrodes, the only gas given off is hydrogen at the cathode. (11%)
		B4	AC17: When dilute aqueous zinc nitrate solution is electrolysed using graphite electrodes, zinc is deposited at the cathode. (11%)
Electroplating an iron spoon	11	A	AC18: In electroplating an iron spoon with silver the spoon should be used as the anode. (39%)
		A1	AC19: In electroplating an iron spoon with silver using aqueous silver nitrate solution as electrolyte, the silver ions (cations) migrate to the anode. (13%)

Electrolysis Reactions	Item No.	Choice	Alternative Conceptions
Purifying an impure copper plate	12	B3	AC20: In purifying an impure copper plate using aqueous copper sulphate solution, the copper(II) ions migrate to the anode. (11%)
Manufacture of chlorine	13	A1	AC21: In the manufacture of chlorine by electrolysis of concentrated aqueous sodium chloride solution using graphite electrodes, hydrogen gas is produced because hydrogen ions are preferably discharged over hydroxide ions. (10%)
		B3	AC22: In the manufacture of chlorine by electrolysis of concentrated aqueous sodium chloride solution using graphite electrodes, hydrogen gas is not produced because no hydrogen ions are present. (14%)
		B4	AC23: In the manufacture of chlorine by electrolysis of concentrated aqueous sodium chloride solution using graphite electrodes, hydrogen gas is not produced because the concentration of hydrogen ions is very low. (13%)
Extraction of aluminium metal from aluminium oxide	14	A1	AC24: In the electrolysis of molten aluminium oxide using graphite electrodes, the anode dissolves in the hot aluminium oxide. (16%)
		B1& B2	AC25: In the electrolysis of molten aluminium oxide using graphite electrodes, the graphite anode does not have to be periodically replaced. (21%)
Effect on the environment by the use of electrolysis in industry	15	A2	AC26: Chemical wastes are released into the environment after proper treatment. (18%)
		B	AC27: The use of electrolysis in industry does not cause pollution of the environment. (32%)
Electroplating in the motor industry	16	B2	AC28: In the motor industry, the metals nickel and chromium are not used for electroplating because the metals do not form a strongly adhering coating. (12%)
Electroplating on cutlery items	17	A1	AC29: Cutlery items are often electroplated with silver and nickel because nickel reacts readily with silver. (10%)

Note: The percentage of students displaying each alternative conception (AC) or non conception (Non C) is indicated in parenthesis)

RESULTS ON CONFIDENCE LEVEL

The number of students who were confident in providing the correct response for each item is higher than the number of students who were not confident, except for Item 4, Item 13 and Item 14. The distribution of the confidence level of students in answering each of the items is shown in Table 7.9.

Table 7.9 Confidence level of students in providing the correct response to each of the items (n = 330)

Item No.	Confidence Level in Providing the Correct Response			
	Not Confident		Confident	
	Number of Students	Percentage	Number of Students	Percentage
Item 1	98	30	232	70
Item 2	93	28	237	72
Item 3	127	39	203	61
Item 4	175	53	155	47
Item 5	162	49	168	51
Item 6	151	46	179	54
Item 7	155	47	175	53
Item 8	163	49	167	51
Item 9	134	41	196	59
Item 10	161	49	169	51
Item 11	136	41	194	59
Item 12	147	45	183	55
Item 13	170	52	160	48
Item 14	184	56	146	44
Item 15	129	39	201	61
Item 16	160	49	170	51
Item 17	150	46	180	54

Students' confidence in arriving at the answers for items 4, 13 and 14 regarding the electrolysis of molten lead(II) bromide, manufacture of chlorine in industry and extraction of aluminium from molten aluminium oxide, respectively, is lower compared to the rest of the items. This trend may be attributed to their anxiety and

fear towards these three items. According to Palmer (2006), an individual's response to their own stress, fear and anxiety is the physiological and affective states of efficacy information.

The rest of the items in which the students were more confident in providing the correct response could be the result of several factors such as the students keeping up-to-date with their work and persistently trying out similar problems to achieve success. Bandura (1997) considered this practice as enactive mastery experiences, one of the four main sources of efficacy information, and is the most influential source of self-efficacy. Similarly Chan and Mousley (2005) agreed that most of the students in their project felt “a need to practice sufficient examples before they developed adequate confidence and curiosity for more independent and diverse ways of solving problems” (p. 223).

Another possible factor could be the encouraging and patient teachers who had always been generous with positive evaluative feedback which is essential for the students to achieve better results. This type of positive evaluative feedback involving verbal persuasion is another source of efficacy information (Bandura, 1997) and is supported by Dalgety, Coll and Jones (2003) who found that during high school, students develop attitudes and efficacy beliefs toward chemistry that they bring to their tertiary-level studies. Howitt (2007) discovered that learning experiences situated with meaningful and authentic contexts have contributed to increased confidence of preservice teachers. Similarly students taught by teachers with this type of experiences will contribute to increased confidence of students.

In the classroom, the students could have modeled the teachers' methods of arriving at the correct answers besides getting help from their friends; this type of self-efficacy perceived by the students as capable of performing favourably in comparison to others is vicarious experiences type of efficacy information (Bandura, 1997).

For the students who answered both parts correctly, as shown in Table 7.10, their confidence was higher than the percentage who selected the correct response on all items except Item 1. Figure 7.2 shows the graphs of both parts answered correctly in

percentage (y_1) and the confidence level in percentage (y_2) for each of the 17 items in the diagnostic instrument.

Table 7.10 The confidence level of students who correctly answered both parts of each item ($N = 330$)

Item No.	Number Who Answered Both Parts Correctly	Both Parts Answered Correctly, y_1 (%)	Confidence Level in Answering Items, y_2 (%)
1	260	79	70
2	175	53	72
3	136	41	61
4	146	44	47
5	64	19	51
6	113	34	54
7	110	33	53
8	125	38	51
9	106	32	59
10	82	25	51
11	145	44	59
12	116	35	55
13	126	38	48
14	102	31	44
15	135	41	61
16	147	45	51
17	164	50	54
	330		

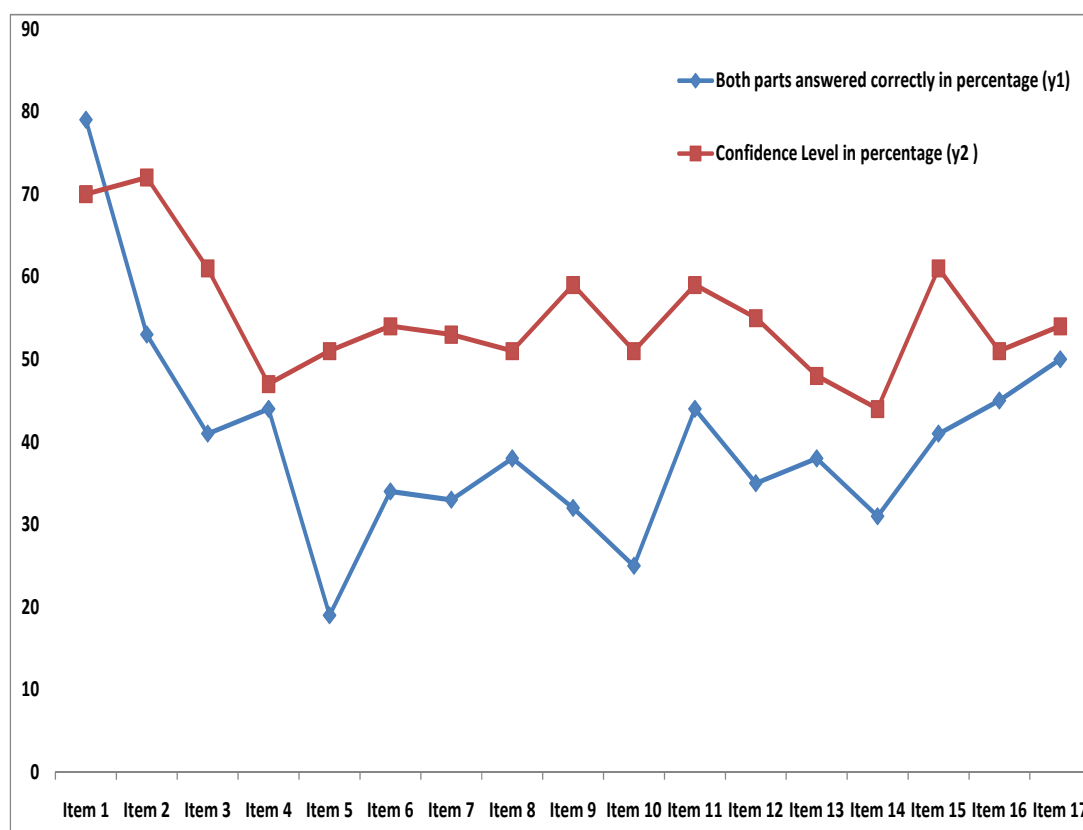


Figure 7.2. Graphs showing both parts answered correctly in percentage and confidence level in percentage for the 17 items in the diagnostic instrument

SUMMARY

The analysis of the 17 items that was reported in the preceding section has revealed that 29 alternative conceptions were held by the Form Four students to whom the instrument was administered. These 29 alternative conceptions, which relate to the students' ability to explain the reactions in electrolysis are summarised in Table 7.8. No alternative conceptions were evident from Item 1.

The second part of this chapter summarised the confidence level of students in answering the 17 items. Students were more confident in arriving at the answers for 14 out of 17 items, not confident in arriving at the answers for 3 out of 17 items and this could be due to several factors as discussed.

CHAPTER EIGHT

CONCLUSIONS, RECOMMENDATIONS AND LIMITATIONS

INTRODUCTION

In this chapter, a brief outline on how the research questions in the study were answered is presented. The information collected during the study provides the basis for the conclusions, recommendations and discussion on the limitations of the study.

SUMMARY OF THE STUDY AND CONCLUSIONS

The six research questions which guided this study on electrolysis were:

1. What are the concepts and propositional knowledge necessary for secondary chemistry students to understand the topic of electrolysis?

Research Question 1 established the content boundaries for the investigations in this study. The content framework for secondary chemistry electrolysis was described in Chapter 3 through a review of the chemistry syllabus, the preparation of a concept map, and a list of propositional statements.

2. Are the concepts and propositional knowledge present in the three approved chemistry textbooks used by secondary chemistry students consistent with the concepts and propositional knowledge identified in the study? Research Question 2 was answered in Chapter 4 where three approved chemistry textbooks were analysed to determine whether the concepts and propositional knowledge present in the three texts were consistent with the concepts and propositional knowledge identified in Chapter 3. It was found that all three texts to a large extent provided sufficient information and explicitly explained the concepts and reactions in electrolysis. The computer software provided by the Curriculum Development Division revealed very clear animations of a number of electrolysis concepts such as the electrolysis of dilute sulphuric acid using carbon electrodes (CD Lesson 52), and the purification of copper

metal using copper(II) sulphate solution (CD Lesson 57). The author suggests that with better linkage of the ideas, this will help to improve students' understanding of electrolysis.

3. What do secondary chemistry students understand about the concepts and propositional knowledge related to electrolysis?

Research Question 3 was answered through the review of literature in Chapter 2, through interviews with secondary students in Study 1 in Chapter 5 and Study 3 in Chapter 6, and through the administration of a test described in Study 2 in Chapter 5.

4. What are the difficulties in developing a diagnostic test consistent with the identified concepts, propositional knowledge and known student alternative conceptions related to electrolysis?

Chapter 6 described the development of the two-tier multiple choice electrolysis diagnostic instrument, the EDI, which was the main focus of Research Question 4. The development of the EDI was based on the procedures described by Treagust (1986, 1988, 1995). The items in the EDI were developed based on the content framework established in Chapter 3, past years' examination questions and the data collected from students in Studies 1 and 2 as discussed in Chapter 5.

5. What is the extent of secondary chemistry students' understanding and alternative conceptions of the concepts and propositional knowledge related to electrolysis as identified through the use of a diagnostic test? Research Question 5 was answered through the administration of the EDI with 17 items to 330 Form Four students from three different secondary schools, and the results, as well as the alternative conceptions identified from the analysis of the results, were described in Chapter 7. A summary of the 29 alternative conceptions listed in Table 7.8 showed that the Form Four students had significant alternative conceptions under the headings 'Direction of electron flow', 'Ions present in the solution', 'Ions moving to the electrode', and 'Electroplating'. The alternative conceptions provided information on the Form Four students' lack of understanding of the concepts in electrolysis and

the incorrect associations made by the students between the various concepts in their attempts to understand the topic.

6. What is the relationship between the confidence level of the students and providing the correct answer? Research Question 6 was answered in the final section of Chapter 7 where the relationship between the confidence level of the students and providing the correct answer was determined between the two variables.

RECOMMENDATIONS

Based on the findings on this study and the literature reviewed in Chapter 2, recommendations for helping students improve their understanding of electrolysis as well as recommendations for further research are given in this section.

Use of diagnostic instrument

By using the diagnostic instrument at the beginning or on completion of the topic on electrolysis, science teachers can achieve better understanding about the nature of students' understanding and the existence of any alternative conceptions or misconceptions in this particular topic being studied (Treagust & Chandrasegaran, 2007). Subsequently, the teacher can act on the feedback to work on the type of remedial or extension work that is deemed necessary. Treagust and Chittleborough (2001) also found that diagnostic tests which have been developed in covalent bonding and structure (Peterson, Treagust & Garnett, 1989), bonding (Tan & Treagust, 1999), chemical equilibrium (Tyson, Treagust & Bucat, 1999) provide an opportunity for teachers to diagnose student learning without the need for interviews.

Appropriate use of models and definitions of new terminology

It is vital for students to get access to correct sources of information in textbooks. Chiu (2007) found that for high school students, the teachers' instruction, textbooks, and teaching materials were the main sources of student conceptions. Teachers should help select the teaching materials such as the appropriate use of models,

illustrations, and definitions of new terminology to help students learn chemistry concepts more effectively.

The special language of chemistry poses problems to the learners (Boo, 1998; Fensham, 1994; Gabel, 1999). In classrooms, often no distinction is made between the scientific meaning and the commonplace meanings of our vocabulary such as precipitation, energy, or bond (Boo, 1998; Fensham, 1994). Confusion and frustration arise when teachers and textbooks use everyday vocabulary in explanations of chemical phenomena assuming that students understand the special chemical meanings of the terms being used (Nakhleh, 1994; Schmidt, 1997). Therefore careful choice of language is very important in the teaching of chemistry. As Andersson (1986) has stressed, lacking the appropriate framework, students may misinterpret the words of teachers and textbook authors giving rise to alternative conceptions. Treagust and Chittleborough (2001) also discussed the difficulties experienced by students in comprehending the specialised language used in chemistry and distinguishing it from the everyday meanings of identical or similar terms.

Understanding the reactions involved in electrolysis

Students might find the reactions involved in electrolysis difficult to understand because they involve “abstract and formal explanations of invisible interactions between particles at a molecular level” (Carr, 1984, p. 97). Nakhleh and Krajcik (1994) explained that in order for a student to engage in chemical reasoning, he or she may need to constantly shift between four representational systems, the macroscopic, submicroscopic, symbolic and algebraic, and this causes further difficulties. The use of multi-media animations also could facilitate the understanding of reactions at the submicroscopic-level (Chiu & Wu, 2009; Chandrasegaran, Treagust & Mocerino, 2005; Treagust & Chandrasegaran, 2007; Garnett et al., 1995; Harrison & Treagust, 1998; Lee, 2007; Sanger & Greenbowe, 1997a; Yochum & Luoma, 1995). A study performed by Sanger and Greenbowe (1997a) suggested that “using computer animations depicting chemical reactions on the molecular level and a teaching approach that confronted student misconceptions dramatically decreased the proportion of students consistently demonstrating that

electrons can travel through aqueous solutions” (p. 396). The teaching software provided by the curriculum department by the Ministry of Education, Malaysia has a good selection of the animations necessary to help the students understand the chemical reactions on the submicroscopic level (or molecular level, as referred to by some researchers), such as the electrolysis of dilute sulphuric acid using carbon electrodes (CD Lesson 52) and the purification of copper metal using copper(II) sulphate solution (CD Lesson 57). This study did not investigate the teaching strategies used by the teachers in the classrooms, and it is anticipated that the Form Four chemistry teachers were able to guide their students to understand the electrolysis concepts at the submicroscopic level. Nevertheless, Treagust and Chittleborough (2001) cautioned that by “simply having access to computer software and multimedia is not enough to affect students learning and without teacher facilitation the resources may not be used to their full potential” (p. 258).

Recommendations for further research

Increasing the number of secondary students to be interviewed would help to identify any further alternative conceptions related to the individual items tested in the diagnostic instrument, besides validating the findings of the results (Peterson, 1986; Tan, 2000).

Replication studies using the EDI should also be conducted with “other samples of learners, particularly in different types of institutions, or even in different education systems” (Taber, 2000, p. 48) to compare the results. A larger Malaysian sample consisting of Form Four students studying chemistry from every state could be carried out to make comparisons. Possible similar samples are students learning about electrochemistry in Singapore, Australia, New Zealand and Hong Kong where the language of instruction is English. Further the instrument could be translated and administered to comparable students in Indonesia, Thailand and Taiwan.

The extent of the application of the multimedia software recommended by the Curriculum Department of Malaysia to teach particular concepts of electrolysis and electrochemistry and the strategies of teachers in illustrating the concepts to the students may be of further interest. These animation methods have also been

recommended by Sanger and Greenbowe (1997b) and Yochum and Luoma (1995) and shown to have greatly improved the students' understanding of the concepts demonstrated.

Future study can explore the Form Four students' confidence in chemistry and the relationship between confidence in chemistry and previous achievement in chemistry to find out more about the pattern of the development of students' confidence in chemistry. Similar studies can be extended to samples of students learning about electrolysis in Singapore, Australia, New Zealand and Hong Kong where the language of instruction is English.

LIMITATIONS

Five limitations have been identified in this study. These are the selected number of concepts and propositions tested in the EDI, the limited size and nature of the sample used in this study, the problems associated with pencil-and-paper tests, the lack of follow-up interviews, and the small number of textbooks analysed.

The concepts and propositions assessed

The focus of this study was on the concepts and propositions that are related to electrolysis, and effort was made by the researcher to include as many concepts and propositions as possible in the electrolysis diagnostic instrument. However, not all concepts and propositions related to the Malaysian School Certificate chemistry syllabus were measured by the EDI. Therefore the conclusions refer specifically only to the concepts and propositions examined by the test items.

Size and nature of the sample

The sample consisted of 330 students from three secondary schools in Kuching, one of the cities in Malaysia. The findings are therefore limited to this sample, and not to the entire Form Four student population in Malaysia. A cross sample study in all Malaysian states for Form Four students studying chemistry may be made possible if there had been greater financial aid.

Problems associated with pencil-and-paper tests

Pencil-and-paper tests have their limitations. Taber (1999a) pointed out that multiple choice tests “make some demands on the reading/comprehension skills of the respondents” (p. 99), and students do not always perceive and interpret test statements in the way that test designers intend (Hodson, 1993). In this study, the sample consisted of students who communicate at home with languages such as English, Mandarin, and other local Malaysian dialects, hence giving rise to demands on the comprehension skills of the respondents when their mother tongue is not English. Students guessing the answers due to the lack of comprehension skills of the language or lack of understanding on the electrolysis concepts will affect the validity and reliability of the test. The limited number of distracters that can be given a question as carried out in this study meant that only the most common alternative conceptions were likely to be diagnosed (Taber, 1999a).

The lack of follow-up interviews

There were no further interviews after the EDI was administered and analysed, hence there was no further identification of alternative conceptions related to the content tested by the items. As the topic of electrolysis is taught in late Semester 2 of Form Four, time was rather limited to conduct further interviews. Follow-up interviews could help to explore further the alternative conceptions held by the students as well as the depth and extent of their correct understanding.

The number of textbooks analysed

Among the number of textbooks used in the secondary schools, only three that were the most frequently used were analysed in this study to determine whether or not they are consistent with the concepts and propositional knowledge statements about electrolysis identified in this study. Therefore the findings in Chapter 4 cannot be generalised for all chemistry textbooks.

SUMMARY

This chapter summarises how the six research questions raised in Chapter 1 were answered. Research Question 1 established the content boundaries for the investigations in this study. Research Question 2 was answered through the analysis of three approved chemistry textbooks which was described in Chapter 4. The review of literature in Chapter 2 answered Research Question 3. Chapter 6 described the development of the two-tier multiple choice electrolysis diagnostic instrument (EDI), which was the main focus of Research Question 4. Research Question 5 was answered through the administration of the EDI to 330 Form Four students, and the results were analysed in Chapter 7, with the identification of 29 alternative conceptions pertaining to electrolysis.

Recommendations for the teaching and learning of electrolysis, including the use of diagnostic instrument, appropriate use of models and definitions of new terminology, and understanding the reactions involved in electrolysis were also discussed.

Among the recommendations for further research, increasing the number of secondary students to be interviewed; replication studies using the EDI with other samples of learners to compare the results; exploring the Form Four students' confidence in chemistry and the relationship between confidence in chemistry and previous achievement in chemistry to find out more about the pattern of the development of students' confidence in chemistry were put forward.

Finally the limitations of the study were also discussed. The limitations included the range of concepts and propositions assessed; the size and nature of the sample; the problems associated with pencil-and-paper tests; the lack of follow-up interviews; and the number of textbooks analysed.

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APPENDIX A

EXTRACT OF THE MALAYSIAN SCHOOL CERTIFICATE

CHEMISTRY SYLLABUS FOR 2008 ON ELECTROLYSIS

The meaning of electrolyte, and electrical conductivity.

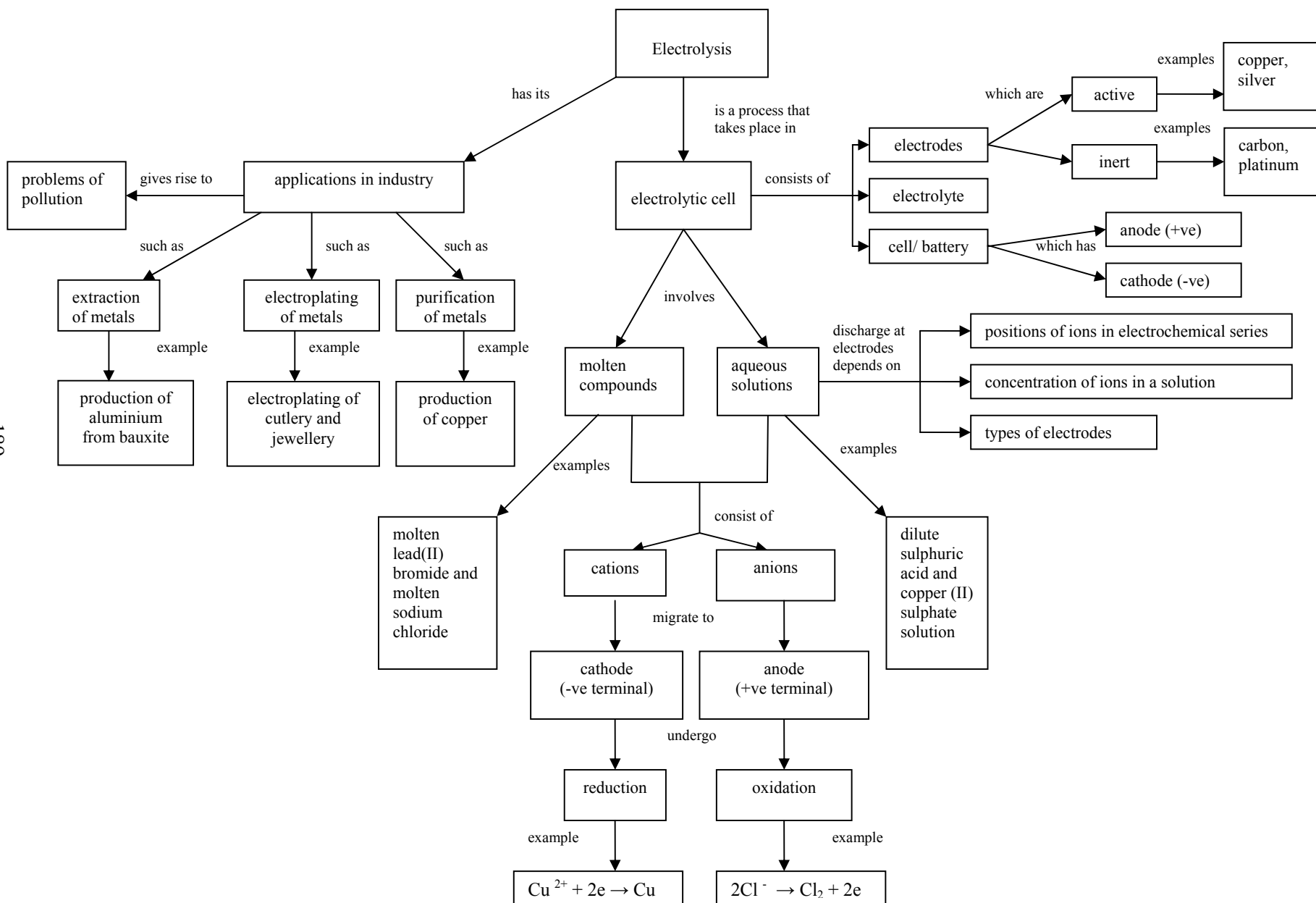
Electrolysis of molten compounds, aqueous solutions.

Identify cations and anions, describe the electrolytic process, write half equations for the discharge of ions at anode and cathode, predict the products from the electrolysis of other molten compounds or aqueous solutions.

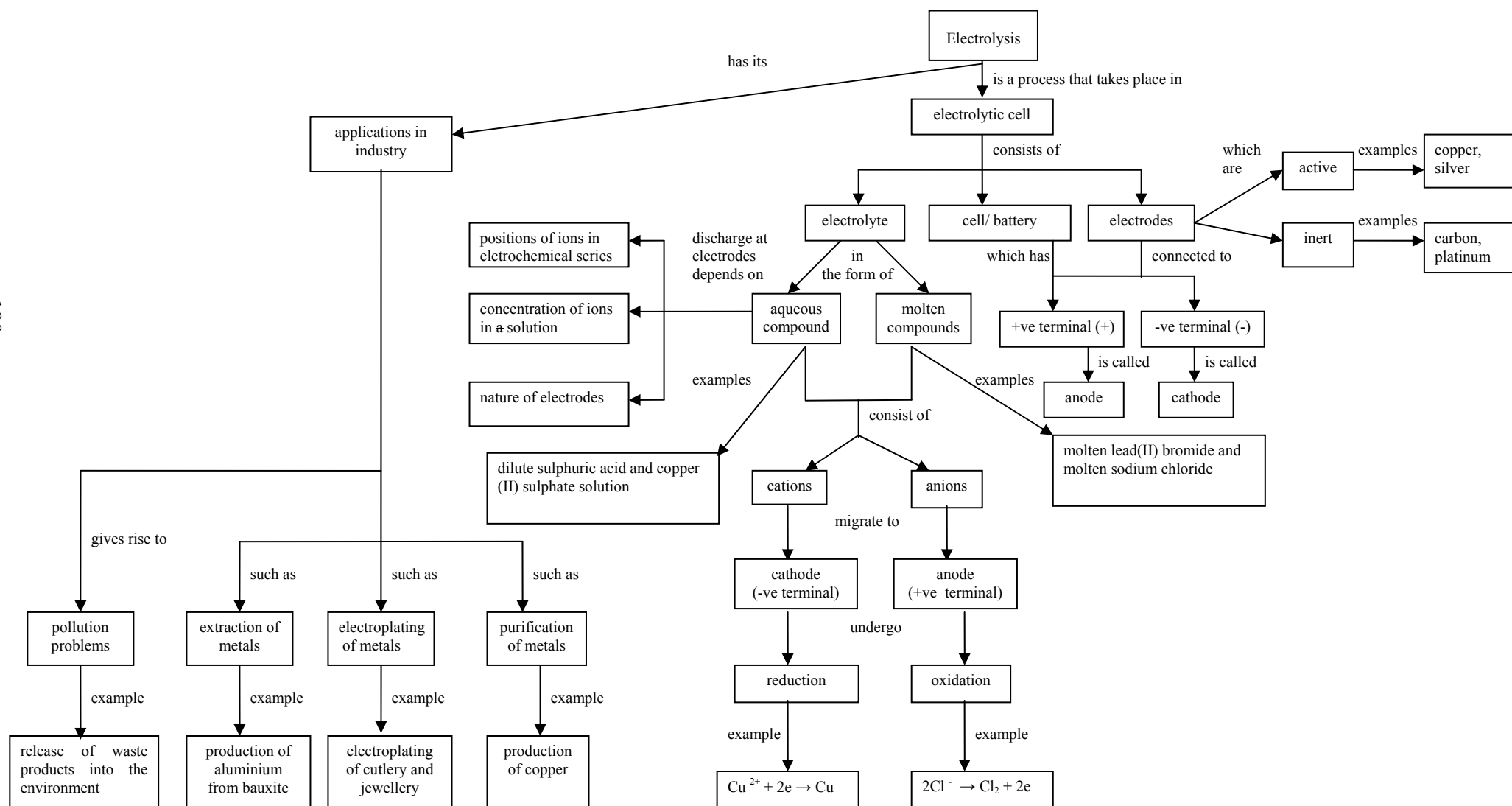
Factors determining selective discharge of ions at electrodes based on position of ions in electrochemical series, concentration of ions in a solution, types of electrodes.

Electrolysis in industry, the purification and electroplating of metals, the benefits and harmful effects of electrolysis in industries.

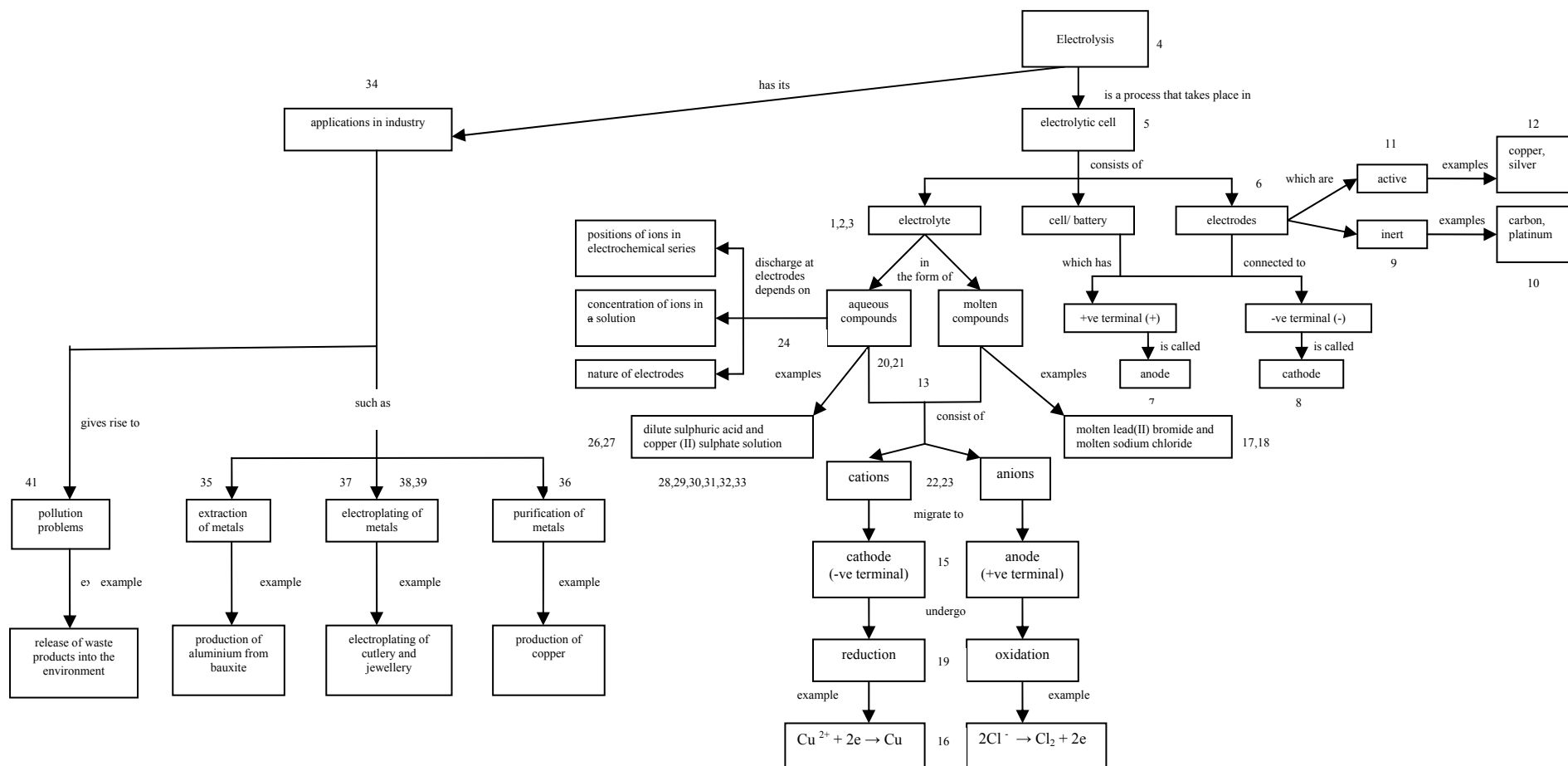
APPENDIX B1: FIRST VERSION OF THE CONCEPT MAP ON ELECTROLYSIS



APPENDIX B2: FINAL CONCEPT MAP ON ELECTROLYSIS



APPENDIX B3: RELATING PROPOSITIONAL KNOWLEDGE STATEMENTS TO THE CONCEPT MAP



APPENDIX C

FREE RESPONSE QUESTIONS ON ELECTROLYSIS

Name: _____

Name of School/College: _____

Class: _____ Age: _____ years Date: _____

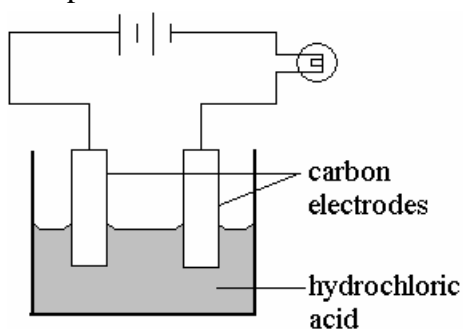
Instructions to Students

This paper consists of 21 questions that evaluate your understanding of electrochemical principles that you have studied in your chemistry course.

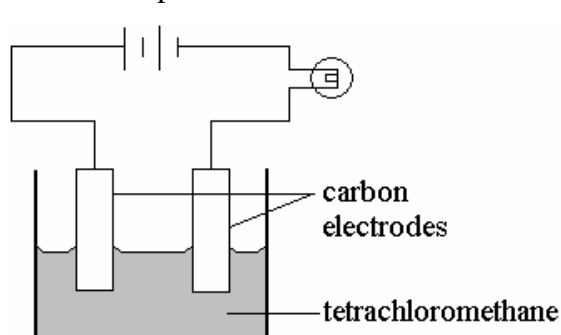
Write your answers in the spaces provided.

1. In which of the following two experiments would you expect the bulb to light up?

Experiment 1



Experiment 2



2. During electrolysis of molten lead(II) bromide using graphite electrodes, reddish fumes of bromine gas and molten lead are produced. At which electrode does oxidation occur?

3. In the manufacture of chlorine by electrolysis of concentrated sodium chloride using graphite electrodes, hydrogen gas is also produced. Is this true or false?

4. In the electrolysis of molten magnesium oxide using carbon electrodes, at which electrode is magnesium produced?

5. When a dilute solution of iron(II) sulphate is electrolysed using platinum electrodes, what happens to the light green colour of the solution?

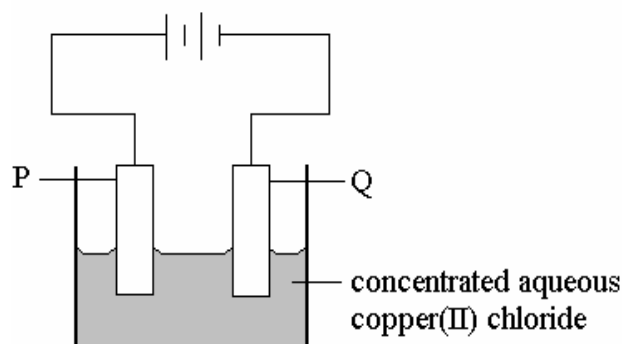
6. What are the products of electrolysis of dilute sulphuric acid using inert electrodes?

7. What will happen initially when aqueous zinc nitrate is electrolysed using graphite electrodes?

8. When dilute sulphuric acid is electrolysed using inert electrodes, what happens to the concentration of the electrolyte?

9. Copper(II) sulphate solution is electrolysed using platinum electrodes, and a reddish-brown deposit is produced at the cathode. What happens to the blue colour of the electrolyte?

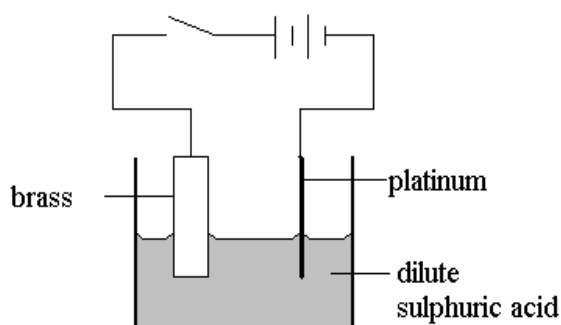
10. The diagram below shows an electrolytic cell in which an electric current passes through a concentrated aqueous solution of copper(II) chloride using inert graphite electrodes.



What happens at the electrode P?

11. In order to electroplate a metal spoon with silver, which substance should be used as the cathode?

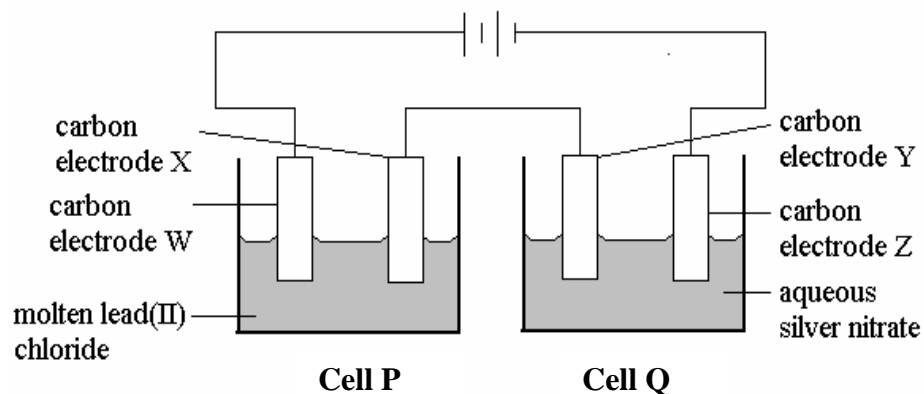
12. Brass is an alloy of copper (60%) and zinc (40%). The diagram shows the apparatus that is used to carry out electrolysis using brass as the anode.



What happens at the electrodes when the circuit is first closed?

13. In order to purify an impure copper plate, which substance must be used as the cathode?

14. The diagram below shows the set-up of apparatus to investigate the electrolysis of molten lead(II) chloride and aqueous silver nitrate.



Which pair of electrodes will increase in mass?

15. In the extraction of aluminium by the electrolysis of molten aluminium oxide using graphite electrodes, which of the electrodes has to be replaced periodically?

16. The use of electrolysis in industry causes pollution as a result of

Items 17 – 19 are three examples in which electrolysis is used in industry for electroplating.

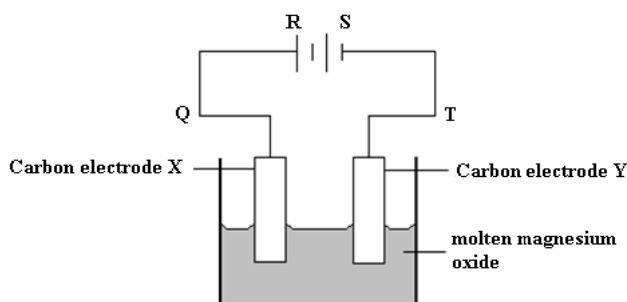
17. In the motor industry, electroplated nickel or chromium is widely used as the coating system. Is this true or false?

18. Cutlery items are often electroplated with silver alone, not with silver and nickel. Is this true or false?

19. Gold-plated wrist watches are more expensive than gold watches. Is this true or false?

Items 20 and 21 refer to the diagram below.

The diagram shows the electrolysis of molten magnesium oxide.



20. Which electrode is the anode?

21. The direction of the movement of electrons is from

APPENDIX D1

INTERVIEW ONE: INTERVIEW QUESTIONS ON ELECTROLYSIS

The semi-structured interviews were conducted in a one-to-one situation, began with the open-ended question:

“What did you find difficult to understand in the work you have done on electrolysis?”

Based on student responses to this question, more specific follow-up questions were asked. Examples of follow-up questions were:

“What part in particular did you find difficult to understand?”

“Why do you find it difficult to understand?”

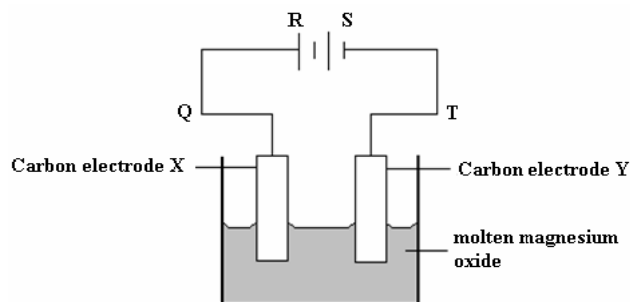
“Can you give an example to help explain what you mean?”

APPENDIX D2

INTERVIEW TWO: INTERVIEW QUESTIONS ON ELECTROLYSIS

Question 1 refers to the diagram below.

The diagram shows the electrolysis of molten magnesium oxide.



(The labelling of positions Q, R, S and T was to serve the purpose of clearer transcribing when referring to the flow of electrons from one position to another, instead of pointing to the diagram, saying “here’ to ‘there’).

Question 1

- 1.1 What is the direction of the flow of electrons in this diagram?
- 1.2 Can you please explain why the electrons flow in this direction?
- 1.3 Which electrode is the anode?

Question 2

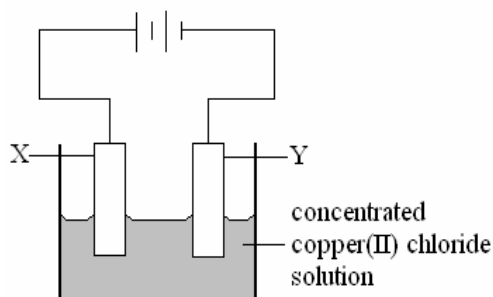
- 2.1. When aqueous iron(II) sulphate is electrolysed using platinum electrodes, what happens to the light green colour of the solution?
- 2.2. Can you explain why the change of colour occurs?

Question 3

- 3.1 When dilute sulphuric acid is electrolysed using inert electrodes, what happens to the concentration of the electrolyte?
- 3.2 Can you explain why the change you have described takes place?

Question 4

The diagram below shows an electrolytic cell in which an electric current passes through a concentrated aqueous solution of copper(II) chloride using inert graphite electrodes.



- 4.1 What is the electrode X, is it anode or cathode?
- 4.2 Can you tell me what happens at the electrode X?
- 4.3 Explain why.

Question 5

- 5.1 Are gold-plated wrist watches more expensive than gold watches?
- 5.2 Why do you think so?

Question 6

- 6.1 In order to electroplate a metal spoon with silver, which of the following should be used as the cathode?
 - (1) A copper strip
 - (2) The spoon
 - (3) A carbon rod
 - (4) A silver strip
- 6.2 Please explain why you chose that answer.

Question 7

- 7.1 Cutlery items are often electroplated with silver alone, not with silver and nickel. Do you agree with this statement?
- 7.2 What is your reason for that?

APPENDIX E1

Transcripts of Interview One with Students S04 and S07

Student S04

- I:** What did you find difficult to understand in the work you have done on electrolysis?
- S04:** Aa..... Electrolysis, yea, the flow of electron or the flow of electric current from the anode to cathode or cathode to anode, from the negative terminal to the positive terminal or positive terminal to the negative terminal, I find it very confusing.
- I:** Which part in particular did you find difficult to understand?
- S04:** The types of ions discharged at each electrode, and it is different, depend on the factor,...factors, the concentration....so if this ion has higher concentration, then other ion discharged, although in higher concentration, normally lower ion is discharged than the one in higher concentration, so.....very confusing.
- I:** So you find that difficult?
- S04:** Yes.
- I:** Thank you very much for your time.
- S04:** Thank you.

Student S07

- I:** Can you please tell me what did you find difficult to understand in the work you have done on electrolysis?
- S07:** For me what I find difficult to understand is the formula and equations that you have to memorise and their reactions. I find it very difficult for me to write the equations on. There are so many formulas and equations.....Very confusing for me.
- I:** Are you referring to the half equations?
- S07:** Yes, half equations, ..yea, combined equations.
- I:** Can you give an example to explain further?
- S07:** Eh....There are many ions, cations and anions. I get confused with many different ions, like for example, sulphide ion and sulphate ion. I don't know which is which.
- I:** Which part in particular did you find difficult to understand?
- S07:** I have to say the electrochemical series. There are so many equations, so many chemicals in the electrochemical series... and you have to remember in the same order, otherwise you get it all wrong.
- I:** Why do you find it difficult?
- S07:** For chemistry you already have to memorise lots of stuff, and then if you have to memorise the electrochemical series in the same order again, it is very confusing and hard to solve.
- I:** Thank you for your time.
- S07:** Thank you.

APPENDIX E2

TRANSCRIPTS OF INTERVIEW TWO WITH STUDENTS S16 AND S25

Student S16

I: Good morning, Can you please explain why you chose the direction of flow of electrons is from X to Y in the electrolyte? Just explain in your own words.

S16: Eh....the direction of the...of the movement of electrons is from.... electrode X to electrode Y in the electrolyte because the movement of the electrons must... from the anode to the cathode which is positive to the negative terminal.

I: Positive to negative.... Right, can you show me where is the positive?

S16: This is positive (electrode X, pointing to the diagram), this is negative (electrode Y), follow the battery.

I: So the electron is flowing through here..... (Electrode Y to X in the electrolyte), what about the outside, the external circuit?

S16: External circuit is Q to T, this way.

I: External circuit is this way, ...(drawing on the diagram to confirm). If you follow like this, then the electrons will be

S16: Oh.....

I: Never mind.....

S16: From.....from Y to X.

I: Y to X, so it's from Y to X, so you are changing your answers from Y to X, this way. Okay. So just to explain this...electron is flowing from positive to negative, and then move on from the electrode Y to electrode X, then it completes like that.

S16: Hmm.....

I: Now, which one has you chosen as the anode?

S16: I chose X, because it is positive terminal.

I: Now, regarding the electrolysis of aqueous iron(II) sulphate using platinum electrodes, what happens to the light green colour of the solution?

S16: It will...it will become fainter because it ionizes in the solution.

I: It ionizes in the solution. Can you tell me what are the ions present in this...solution?Ions present?

S16:don't know.

I: Talking about electrolysis of dilute sulphuric acid, this one you have learnt in your lesson, right?

S16: Yes.

I: When dilute sulphuric acid is electrolysed using inert electrodes, what happens to the concentration of the electrolyte?

S16: The concentration of the electrolyte remains unchanged because it is using the inert electrode which is unreactive electrode.

I: Unreactive.....For this one, do you remember what are the ions present there?

S16:I can't remember.

I: Now when you...when you look at this one, electrolysis of concentrated copper(II) chloride solution here, what is electrode X? Anode or cathode?

S16: It is the anode.

I: Now, what happens at this electrode?

S16:Ah.....the copper(II) ion are oxidized.

I: Do you have any reason for that?

S16: Because it gains electrons...ah....loss of electrons.

I: Now how much do you know about gold-plated wrist watches... are they more expensive than gold watches?

S16: True, yes.

I: What makes you think so?

S16: Because it is more pure than the gold watches and does not mix with other metal.

I: Gold-plated wrist watches are more pure, right?

S16: Yes.

I: Now to electroplate a metal spoon with silver, which one you use as the cathode?

S16: A silver ion ...a silver strip.

I: Why do you choose the silver strip?

S16: Because ...a silver strip....in order to elect....electroplate a metal spoon with silver, it should use a silver strip to make it more shiny.

I: More shiny,....do you understand the movement of ions here?

S16: If I'm not mistaken lah, eh.....

I: Okay, you try to explain.

S16: The ...the....the silver strip will ionize in water, ...in the solution, the metal spoon....the metal spoon will get more shynylah.

I: So the metal spoongets the silver ions?

S16: Yes.

I: So for cutlery items they are often electroplated with silver alone, not with silver and nickel. Do you agree with this?

S16: Yes.

I: So what is your reason for that?

S16: It is because if the cutlery items are often elect...elect....electroplated with the silver and nickel, the cutlery will rust.

I: If with silver alone?

S16: No, it won't rust with silver alone.

I: Thanks for your time.

S16: Thank you.

Student S25

I: Good morning, ... I would like to know why you think the electron flow is from electrode Y to X in the electrolyte (pointing to the diagram)?

S25: Because em...we all know that the current is from the positive terminal to the negative terminal. So it should be that the electron which has the opposite charge flows in the opposite way.

I: Now, do you think the electrons also flow through this electrolyte?

S25: Yes (confident tone).

I: What about electron flow from the ...external circuit? Here, right. Now, you have chosen this one (electrode X) as the anode, and because it's connected to the

S25: Positive terminal (of the battery).

I: Okay.

- I:** Now, why do you think the green colour becomes fainter?
- S25:** Because em....the platinum is not an inert electrode, so it involves a lot of chemical reaction plus the ions in the solution and the intensity of the iron decrease.
- I:** So platinum is, is that inert or not inert?
- S25:** Not inert.
- I:** Not inert? Then when you electrolyse dilute sulphuric acid using inert electrodes, so the concentration of the electrolyte remains.....?
- S25:** Unchanged.
- I:** So your reason is?
- S25:** Because inert electrode does not take part in the reactions so there is no chemical reaction at the electrode.
- I:** Now for a concentrated aqueous solution of copper(II) chloride, what are the ions present?
- S25:** The copper ion, chloride... ions, hydroxide and... hydrogen ions.
- I:** What happens to the chloride ions?
- S25:** The chloride ions are reduced.
- I:** Why do you choose that to be reduced?
- S25:** Because em....the chloride ions is the negative ion, so it is attracted to the positive which is the anode. And then, in order to become,....in order to... make less of the charges, so it has to gain electrons... to be reduced.
- I:** Then for the gold-plated wrist watches, you feel they are...they are more expensive than gold watches?
- S25:** Much cheaper.
- I:** Much cheaper. What is your reason?

S25: Only a small amount of gold is plated.

I: Can you look at the other question, to electroplate a metal spoon with silver, which would you use as the cathode?

S25: The spoon.

I: What is your main reason for choosing the spoon?

S25: The silver will be deposited at the cathode.

I: Now, another question. Cutlery items are often plated with silver alone, not with silver and nickel. Is this true or not?

S25:(Thinking)..... False.

I: False...so what would be your reason?

S25: Usually electroplate with alloy,.....

I: With what?

S25: With alloy, ...

I: What other reason can you think of electroplating with alloy?

S25:(long pause).....Silver is too expensive.

I: Okay, thanks very much.

S25: Thank you.

APPENDIX F1

FIRST VERSION OF FREE RESPONSE INSTRUMENT ON ELECTROLYSIS

Name: _____

Name of School/College: _____

Class: _____ Age: _____ years Date: _____

Instructions to Students

This paper consists of 21 items that evaluate your understanding of electrochemical principles that you have studied in your chemistry course.

Each of the items in this paper consists of two parts.

- In the first part of each item, circle one of the **choices** to indicate what you consider to be the most appropriate answer. **The items may have 1, 2, 3 or 4 choices.**
- In the second part, you are required to provide an explanation for the particular **choice** that you have selected.

Example of an item:

An electrolytic cell has an iron anode and a copper cathode. During electrolysis, the anode decreases in mass.

1 True 2 False

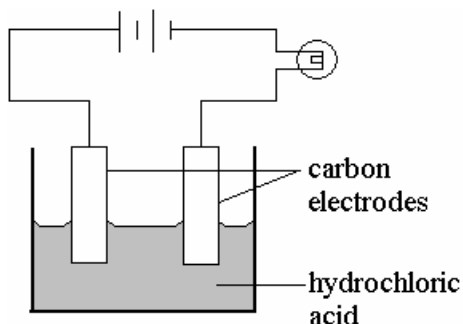
Example of a reason:

Metallic iron produces ions in aqueous solution more readily than does copper.

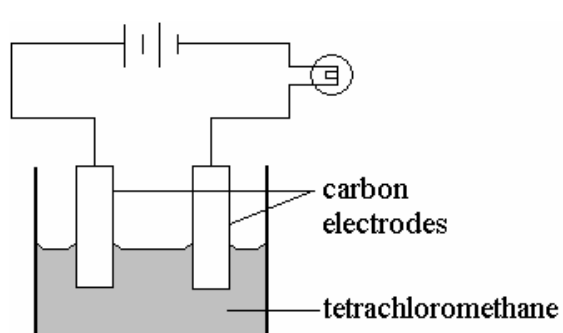
Remember it is important to provide a reason for selecting a particular answer in each item.

1. In which of the following two experiments would you expect the bulb to light up?

Experiment 1



Experiment 2



- (1) Experiment 1
(2) Experiment 2

Reason:

2. During electrolysis of molten lead(II) bromide using graphite electrodes, reddish fumes of bromine gas and molten lead are produced. At which electrode does oxidation occur?

- (1) At the cathode
(2) At the anode

Reason:

3. In the manufacture of chlorine by electrolysis of concentrated sodium chloride using graphite electrodes, hydrogen gas is also produced.

- (1) True
(2) False

Reason:

4. In the electrolysis of molten magnesium oxide using carbon electrodes, at which electrode is magnesium produced?

- (1) At the cathode
(2) At the anode

Reason:

5. When a dilute solution of iron(II) sulphate is electrolysed using platinum electrodes, what happens to the light green colour of the solution?

The colour of the solution

- (1) becomes darker.
(2) becomes fainter.
(3) remains the same.

Reason:

6. What are the products of electrolysis of dilute sulphuric acid using inert electrodes?

	<i>Product at anode</i>	<i>Product at cathode</i>
(1)	Hydrogen	Oxygen
(2)	Water vapour	Sulphur dioxide
(3)	Oxygen	Hydrogen
(4)	Sulphur dioxide	Oxygen

Reason:

7. What will happen initially when aqueous zinc nitrate is electrolysed using graphite electrodes?

- (1) The concentration of the zinc nitrate solution increases
- (2) Effervescence occurs only at the cathode
- (3) The mass of the anode decreases
- (4) The mass of the cathode increases

Reason:

8. When dilute sulphuric acid is electrolysed using inert electrodes, what happens to the concentration of the electrolyte?

The concentration of the electrolyte

- (1) remains unchanged.
- (2) increases.
- (3) decreases.

Reason:

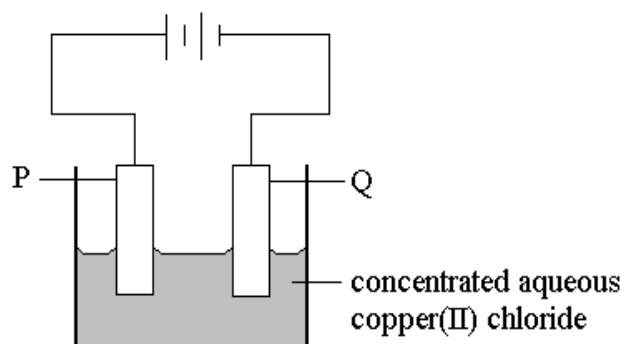
9. Copper(II) sulphate solution is electrolysed using platinum electrodes, and a reddish-brown deposit is produced at the cathode. What happens to the blue colour of the electrolyte?

The colour of the electrolyte

- (1) increases in intensity.
- (2) decreases in intensity.
- (3) remains unchanged.

Reason:

10. The diagram below shows an electrolytic cell in which an electric current passes through a concentrated aqueous solution of copper(II) chloride using inert graphite electrodes.



Which of the following occurs at electrode P?

- (1) Copper(II) ions are reduced
- (2) Copper(II) ions are oxidised
- (3) Chloride ions are oxidised
- (4) Chloride ions are reduced

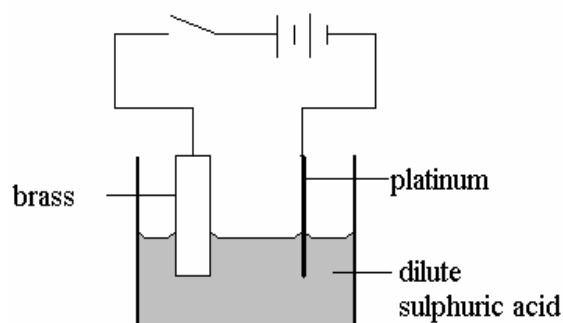
Reason:

11. In order to electroplate a metal spoon with silver, which of the following should be used as the cathode?

- (1) A copper strip
- (2) The spoon
- (3) A carbon rod
- (4) A silver strip

Reason:

12. Brass is an alloy of copper (60%) and zinc (40%). The diagram shows the apparatus that is used to carry out electrolysis using brass as the anode.



What happens at the electrodes when the circuit is first closed?

- | | <i>Anode</i> | <i>Cathode</i> |
|-----|--------------------------|---------------------------|
| (1) | Zinc and copper dissolve | Copper is deposited |
| (2) | Zinc dissolves | Hydrogen gas is liberated |
| (3) | Copper dissolves | Oxygen gas is liberated |
| (4) | Copper dissolves | Hydrogen gas is liberated |

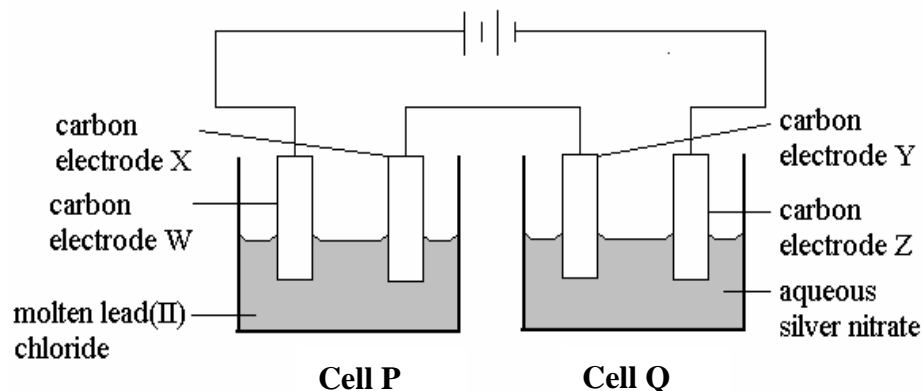
Reason:

13. In order to purify an impure copper plate, which of the following must be used as the cathode?

- (1) An impure copper plate
(2) A pure copper plate

Reason:

14. The diagram below shows the set-up of apparatus to investigate the electrolysis of molten lead(II) chloride and aqueous silver nitrate.



Which pair of electrodes will increase in mass?

- (1) W and Y
(2) X and Z

Reason:

15. In the extraction of aluminium by the electrolysis of molten aluminium oxide using graphite electrodes, which of the electrodes has to be replaced periodically?

- (1) Anode
(2) Cathode

Reason:

16. The use of electrolysis in industry causes pollution as a result of

- (1) the release of poisonous gases like chlorine into the environment.
- (2) chemical wastes, such as cadmium ion and nickel ion, from the electrolytic industries released into the water sources.
- (3) proper treatment of the chemical wastes before they are released into the environment.

Reason:

Items 17 – 19 are three examples in which electrolysis is used in industry for electroplating.

17. In the motor industry, electroplated nickel or chromium is widely used as the coating system.

- (1) True
- (2) False

Reason:

18. Cutlery items are often electroplated with silver alone, not with silver and nickel.

- (1) True
- (2) False

Reason:

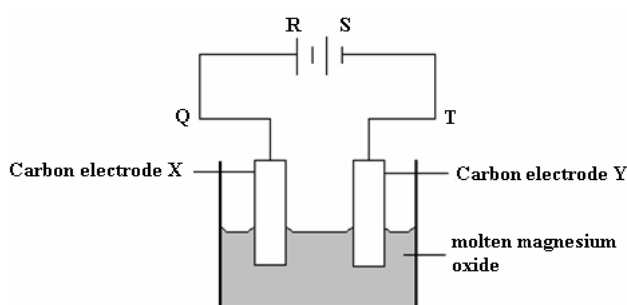
19. Gold-plated wrist watches are more expensive than gold watches.

- (1) True
- (2) False

Reason:

Items 20 and 21 refer to the diagram below.

The diagram shows the electrolysis of molten magnesium oxide.



20. Which electrode is the anode?

- (1) Electrode X
- (2) Electrode Y

Reason:

21. The direction of the movement of electrons is from

- (1) R to Q in the external circuit.
- (2) S to T in the external circuit.
- (3) electrode X to electrode Y in the electrolyte.
- (4) electrode Y to electrode X in the electrolyte.

Reason:

APPENDIX F2

SECOND VERSION OF FREE RESPONSE INSTRUMENT ON ELECTROLYSIS

Name:

Name of School/College:

Class: _____ Age: _____ years Date: _____

Instructions to Students

This paper consists of 21 items that evaluate your understanding of electrochemical principles that you have studied in your chemistry course.

Each of the items in this paper consists of two parts.

- In the first part of each item, circle one of the **choices** to indicate what you consider to be the most appropriate answer. **The items may have 1, 2, 3 or 4 choices.**
- In the second part, you are required to provide an explanation for the particular **choice** that you have selected.

Example of an item:

An electrolytic cell has an iron anode and a copper cathode. During electrolysis, the anode decreases in mass.

1 True 2 False

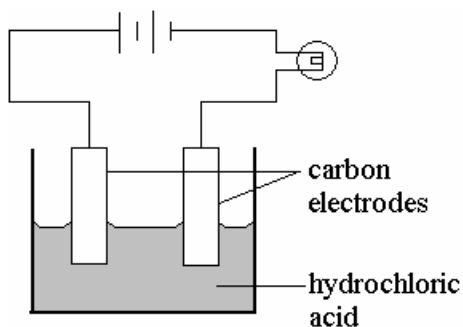
Example of a reason:

Metallic iron produces ions in aqueous solution more readily than does copper.

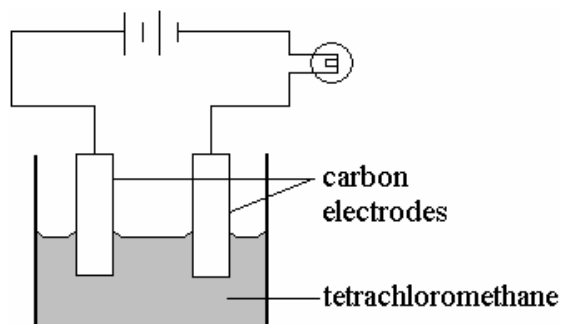
Remember it is important to provide a reason for selecting a particular answer in each item.

1. In which of the following two experiments would you expect the bulb to light up?

Experiment 1



Experiment 2



- (1) Experiment 1
(2) Experiment 2

Reason:

2. During electrolysis of molten lead(II) bromide using graphite electrodes, reddish fumes of bromine gas and molten lead are produced. At which electrode does oxidation occur?

- (1) At the cathode
(2) At the anode

Reason:

3. In the manufacture of chlorine by electrolysis of concentrated aqueous sodium chloride using graphite electrodes, hydrogen gas is also produced.

- (1) True
(2) False

Reason:

4. In the electrolysis of molten magnesium oxide using carbon electrodes, at which electrode is magnesium produced?

- (1) At the cathode
(2) At the anode

Reason:

5. When aqueous iron(II) sulphate is electrolysed using platinum electrodes, what happens to the light green colour of the solution?

The colour of the solution

- (1) becomes darker.
(2) becomes fainter.
(3) remains the same.

Reason:

6. What are the products of electrolysis of dilute sulphuric acid using inert electrodes?

	<i>Product at anode</i>	<i>Product at cathode</i>
(1)	Hydrogen	Oxygen
(2)	Water vapour	Sulphur dioxide
(3)	Oxygen	Hydrogen
(4)	Sulphur dioxide	Oxygen

Reason:

7. What will happen when aqueous zinc nitrate is electrolysed using graphite electrodes?

- (1) The concentration of the zinc nitrate solution increases
- (2) Effervescence occurs only at the cathode
- (3) The mass of the anode decreases
- (4) The mass of the cathode increases

Reason:

8. When dilute sulphuric acid is electrolysed using inert electrodes, what happens to the concentration of the electrolyte?

The concentration of the electrolyte

- (1) remains unchanged.
- (2) increases.
- (3) decreases.

Reason:

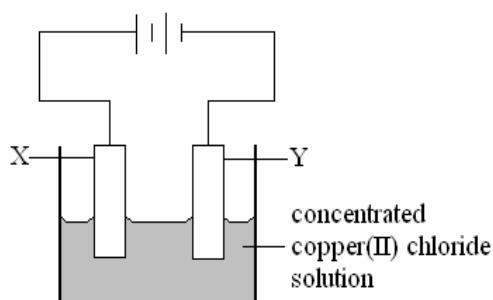
9. Aqueous copper(II) sulphate is electrolysed using platinum electrodes, and a reddish-brown deposit is produced at the cathode. What happens to the blue colour of the electrolyte?

The colour of the electrolyte

- (1) increases in intensity.
- (2) decreases in intensity.
- (3) remains unchanged.

Reason:

10. The diagram below shows an electrolytic cell in which an electric current passes through a concentrated aqueous solution of copper(II) chloride using inert graphite electrodes.



Which of the following occurs at electrode X?

- (1) Copper(II) ions are reduced
- (2) Copper(II) ions are oxidised
- (3) Chloride ions are oxidised
- (4) Chloride ions are reduced

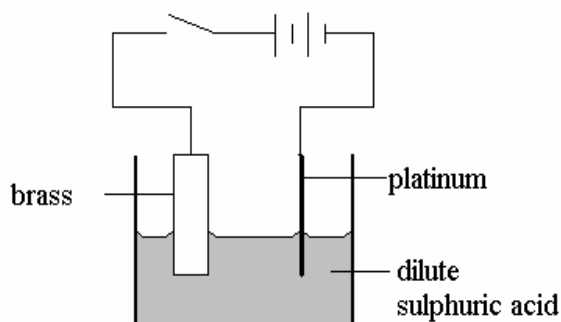
Reason:

11. In order to electroplate a metal spoon with silver, which of the following should be used as the cathode?

- (1) A copper strip
- (2) The spoon
- (3) A carbon rod
- (4) A silver strip

Reason:

12. Brass is an alloy of copper (60%) and zinc (40%). The diagram shows the apparatus that is used to carry out electrolysis using brass as the anode.



What happens at the electrodes when the circuit is first closed?

	<i>Anode</i>	<i>Cathode</i>
(1)	Zinc and copper dissolve	Copper is deposited
(2)	Zinc dissolves	Hydrogen gas is liberated
(3)	Copper dissolves	Oxygen gas is liberated
(4)	Copper dissolves	Hydrogen gas is liberated

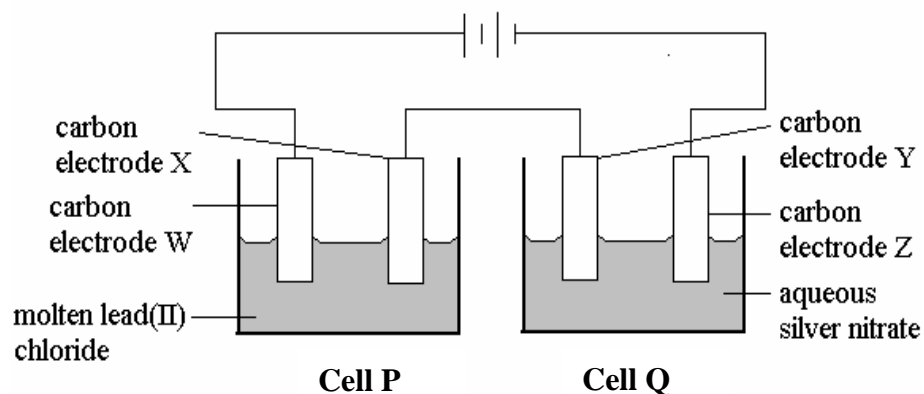
Reason:

13. In order to purify an impure copper plate, which of the following must be used as the cathode?

- (1) An impure copper plate
- (2) A pure copper plate
- (3) A carbon rod

Reason:

14. The diagram below shows the set-up of apparatus to investigate the electrolysis of molten lead(II) chloride and aqueous silver nitrate.



Which electrode will increase in mass?

- | | |
|-------|-------|
| (1) W | (3) Y |
| (2) X | (4) Z |

Reason:

15. In the extraction of aluminium by the electrolysis of molten aluminium oxide using graphite electrodes, which of the electrodes has to be replaced periodically?

- | |
|-------------|
| (1) Anode |
| (2) Cathode |

Reason:

16. The use of electrolysis in industry causes pollution as a result of

- (1) the release of poisonous gases like chlorine into the environment.
- (2) chemical wastes, such as cadmium ion and nickel ion, from the electrolytic industries released into the water sources.
- (3) proper treatment of the chemical wastes before they are released into the environment.

Reason:

Items 17 – 19 are three examples in which electrolysis is used in industry for electroplating.

17. In the motor industry, electroplated nickel or chromium is widely used as the coating system.

- (1) True
- (2) False

Reason:

18. Cutlery items are often electroplated with silver alone, not with silver and nickel.

- (1) True
- (2) False

Reason:

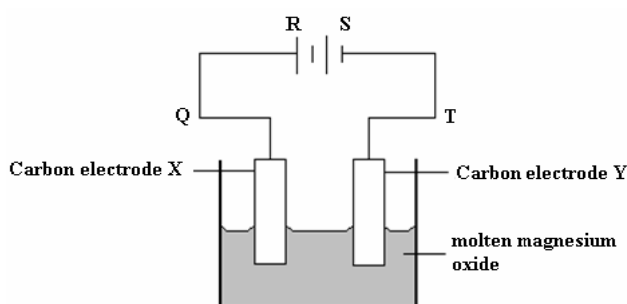
19. Gold-plated wrist watches are more expensive than gold watches.

- (1) True
- (2) False

Reason:

Items 20 and 21 refer to the diagram below.

The diagram shows the electrolysis of molten magnesium oxide.



20. Which electrode is the anode?

- (1) Electrode X
- (2) Electrode Y

Reason:

21. The direction of the movement of electrons is from

- (1) R to Q in the external circuit
- (2) S to T in the external circuit
- (3) electrode X to electrode Y in the electrolyte
- (4) electrode Y to electrode X in the electrolyte

Reason:

APPENDIX F3

SOLUTIONS TO THE FIRST VERSION OF THE FREE RESPONSE INSTRUMENT ON ELECTROLYSIS

(APPENDIX F1)

	Item Number	Content Choice
	1	(1)
	2	(2)
	3	(1)
	4	(1)
	5	(1)
	6	(3)
	7	(1)
	8	(2)
	9	(2)
	10	(3)
	11	(2)
	12	(2)
	13	(2)
	14	(2)
	15	(1)
	16	(2)
	17	(1)
	18	(2)
	19	(2)
	20	(1)
	21	(2)

APPENDIX F4

SOLUTIONS TO THE SECOND VERSION OF THE FREE RESPONSE INSTRUMENT ON ELECTROLYSIS

(APPENDIX F2)

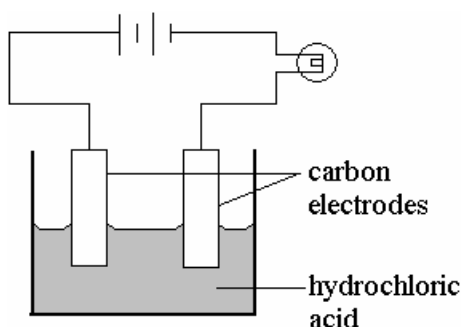
	Item Number	Content Choice
	1	(1)
	2	(2)
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	8	(2)
	9	(2)
	10	(3)
	11	(2)
	12	(2)
	13	(2)
	14	(4)
	15	(1)
	16	(2)
	17	(1)
	18	(2)
	19	(2)
	20	(1)
	21	(2)

APPENDIX G1

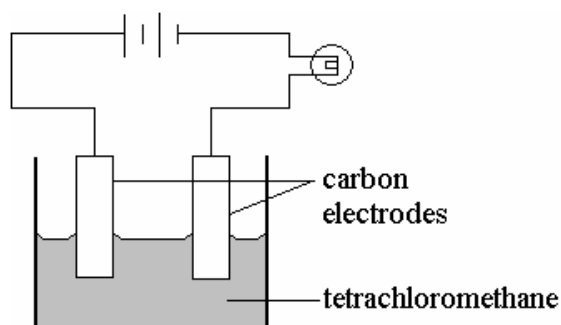
FIRST VERSION OF THE TWO-TIER MULTIPLE-CHOICE DIAGNOSTIC INSTRUMENT

1. In the following two experiments you would expect the bulb in Experiment 1 to light up.

Experiment 1



Experiment 2



- (A) True
(B) False

Reason:

- (1) Tetrachloromethane contains more ions.
- (2) Tetrachloromethane is a covalent compound.
- (3) Hydrochloric acid consists of free moving ions.
- (4) Hydrochloric acid reacts with carbon electrodes to complete the circuit.

2. During electrolysis of molten lead(II) bromide using graphite electrodes, reddish fumes of bromine gas and molten lead are produced. Oxidation occurs at the cathode.

- (A) True
(B) False

Reason:

- (1) Bromine ions move to cathode, therefore oxidation occurs at the cathode.
- (2) Bromide ions lose electrons to form bromine molecules at the anode.
- (3) Lead ion is positive, it moves to the cathode.
- (4) Oxygen is attracted to the anode.

3. In the manufacture of chlorine by electrolysis of concentrated aqueous sodium chloride using graphite electrodes, hydrogen gas is also produced.

- (A) True
(B) False

Reason:

- (1) Hydrogen ions are preferably discharged over hydroxide ions.
- (2) Hydrogen ions are selectively discharged over sodium ions.
- (3) Aqueous sodium chloride does not contain hydrogen ions.
- (4) Only chlorine gas is released.

4. In the electrolysis of molten magnesium oxide using carbon electrodes, magnesium is produced at the anode.

- (A) True
(B) False

Reason:

- (1) Magnesium ions move towards the anode.
- (2) Magnesium ions has negative charge, so they are attracted to the negative terminal.
- (3) Magnesium ions receive electrons that are released from the anode to produce magnesium metal at the cathode.
- (4) Magnesium ions are cations, so they are attracted to the cathode which is negatively charged.

5. When aqueous iron(II) sulphate is electrolysed using platinum electrodes, the light green colour of the solution becomes fainter.

- (A) True
(B) False

Reason:

- (1) Neither iron(II) ions nor sulphate ions are discharged.
- (2) Hydrogen and hydroxide ions are discharged, but iron(II) ions are not discharged at the cathode, hence the colour remains the same.
- (3) Hydrogen and hydroxide ions are decreasing, thus the concentration of solution increases and the colour becomes darker.
- (4) Concentration of iron(II) ions decreases as iron gets deposited at cathode, therefore the green colour of the solution becomes fainter.

6. The products of electrolysis of dilute sulphuric acid using inert electrodes are hydrogen at the cathode and oxygen at the anode.

- (A) True
(B) False

Reason:

- (1) Sulphuric acid releases sulphur dioxide.
- (2) Sulphur dioxide is a cation, it gets deposited at the anode, whereas oxygen gas is an anion, so it gets deposited at the cathode.
- (3) Contains hydrogen and oxygen ions.
- (4) Hydrogen ions and hydroxide ions are selectively discharged.

7. When aqueous zinc nitrate is electrolysed using graphite electrodes, effervescence occurs only at the cathode.

- (A) True
(B) False

Reason:

- (1) H^+ and OH^- are selectively discharged over Zn^{2+} and NO_3^- ions.
- (2) Hydrogen is released at the cathode, thus effervescence occurs.
- (3) Reaction occurs between zinc ions and the graphite electrodes.
- (4) Zinc is deposited at the cathode.

8. When dilute sulphuric acid is electrolysed using inert electrodes, the concentration of the electrolyte increases.

- (A) True
(B) False.

Reason:

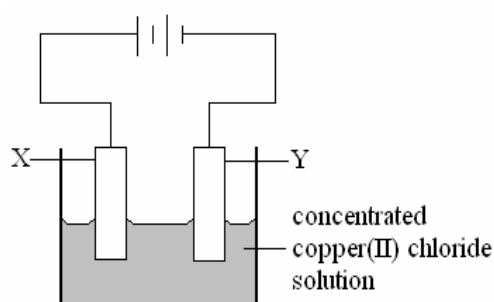
- (1) Hydrogen and oxygen are selectively discharged, so the concentration of the acid decreases.
- (2) H^+ from acid is discharged to form hydrogen gas, thus the concentration of the acid decreases.
- (3) 4H^+ and 4OH^- are released at the same time, so the concentration remains the same.
- (4) OH^- and H^+ ions are discharged. Volume of water decreases thus the concentration of the electrolyte increases.

9. Aqueous copper(II) sulphate is electrolysed using platinum electrodes, and a reddish-brown deposit is produced at the cathode. The blue colour of the electrolyte remains unchanged.

- (A) True
(B) False.

Reason:

- (1) Copper(II) ions are discharged and deposited at cathode, so the colour of the electrolyte decreases in intensity.
 - (2) Copper(II) ions are displaced by platinum, so the colour of the electrolyte decreases in intensity.
 - (3) Platinum dissolves in the electrolyte, so the colour of the electrolyte increases in intensity.
 - (4) Platinum electrodes are inert, so the colour of the electrolyte remains the same.
10. The diagram below shows an electrolytic cell in which an electric current passes through a concentrated aqueous solution of copper(II) chloride using inert graphite electrodes.



At electrode X, chloride ions are oxidised.

- (A) True
(B) False

Reason:

- (1) Copper(II) ions are attracted to X and reduced.
- (2) Copper(II) ions are oxidised. Copper(II) ions are positive, X is negative.
- (3) Chloride ions are oxidised. Chloride ions are being discharged because of higher concentration than hydroxide ions.
- (4) Chloride ions are reduced at cathode. Chloride ions are being discharged because of higher concentration than hydroxide ions.

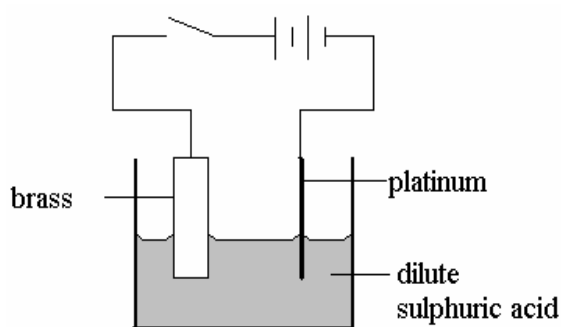
11. In order to electroplate a metal spoon with silver using a silver nitrate as electrolyte, a silver strip should be used as the cathode.

- (A) True
- (B) False

Reason:

- (1) A copper strip is suitable.
- (2) The spoon is suitable as silver ions will be attracted to it at the cathode.
- (3) A carbon rod is suitable as the cathode.
- (4) The silver strip because only silver ions can electroplate the spoon.

12. Brass is an alloy of copper (60%) and zinc (40%). The diagram shows the apparatus that is used to carry out electrolysis using brass as the anode.



When the circuit is first closed, zinc dissolves at the anode and hydrogen gas is liberated at the cathode.

- (A) True
- (B) False

Reason:

- (1) Zinc and copper dissolve at the anode because zinc and copper are more electropositive than hydrogen. Copper is lower than zinc, copper ions from the anode is deposited as copper at the cathode.
- (2) Zinc is more electropositive than copper.
- (3) Copper dissolves at the anode and oxygen gas is liberated at the cathode as copper is lower than zinc.
- (4) Copper dissolves at the anode and hydrogen gas is liberated at the cathode as copper is lower than zinc.

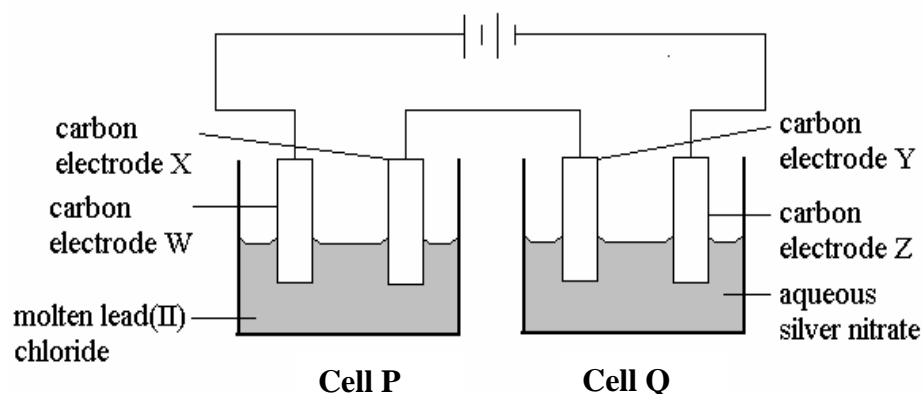
13. In order to purify an impure copper plate, a carbon rod must be used as the cathode.

- (A) True
- (B) False

Reason:

- (1) An impure copper plate must be used because copper ions from the solution will receive electrons to form pure copper at the cathode.
- (2) A pure copper plate must be used because copper ions from the solution will receive electrons to form pure copper at the cathode.
- (3) An impure copper plate must be used because electrons move from the anode to the cathode.
- (4) A carbon rod because impurities on copper plate will be dissolved.

14. The diagram below shows the set-up of apparatus to investigate the electrolysis of molten lead(II) chloride and aqueous silver nitrate.



The electrode X will increase in mass.

- (A) True
- (B) False

Reason:

- (1) Lead is a heavy metal which has high surface tension.
- (2) Lead will be deposited at X, the cathode in Cell P.
- (3) Silver will be collected at electrode Y.
- (4) Silver will be collected at electrode Z, the cathode in Cell Q.

15. In the extraction of aluminium by the electrolysis of molten aluminium oxide using graphite electrodes, the anode electrode has to be replaced periodically.

- (A) True
- (B) False

Reason:

- (1) Anode dissolves to give aluminium ions to be discharged and deposited at the cathode.
- (2) Oxygen gas reacts with carbon to form carbon dioxide, hence carbon electrode erodes over time.
- (3) Electrode becomes smaller, as ions from the anode go to the cathode.
- (4) To avoid overheating that will disrupt the extraction.
- (5) Mass of the anode will decrease.

16. The use of electrolysis in industry causes pollution of the environment.

- (A) True
- (B) False

Reason:

- (1) Electrolytic processes produce poisonous gases such as chlorine.
- (2) Chloride ions are selectively discharged into the environment.
- (3) Chemical wastes such as cadmium ions contaminate the water sources.
- (4) Chemical wastes undergo proper treatment before they are released into the environment.

Items 17 – 19 are three examples in which electrolysis is used in industry for electroplating.

17. In the motor industry, electroplated nickel or chromium is widely used as the coating system.

- (A) True
- (B) False

Reason:

- (1) Nickel and chromium are cheap and affordable.
- (2) The coating gives a shiny surface and can prevent rusting.
- (3) Nickel and chromium are not suitable for electroplating.
- (4) Nickel and chromium have high boiling and melting point.

18. Cutlery items are often electroplated with silver alone, not with silver and nickel.

- (A) True
- (B) False

Reason:

- (1) Silver is too expensive.
- (2) Alloy is less brittle.
- (3) To prevent from rusting.
- (4) It will affect human health if electroplated with nickel.

19. Gold-plated wrist watches are more expensive than gold watches.

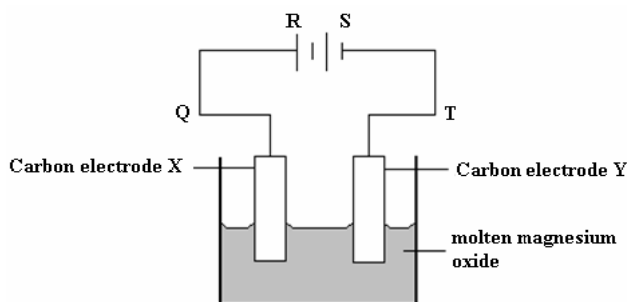
- (A) True
- (B) False

Reason:

- (1) The process of electroplating is troublesome and complicated.
- (2) Gold-plated is a thin layer of gold covering the object.
- (3) Gold-plated is made up of gold metal, more gold is used.
- (4) Gold-plated have better quality.

Items 20 and 21 refer to the diagram below.

The diagram shows the electrolysis of molten magnesium oxide.



20. Electrode X is the anode.

- (A) True
- (B) False

Reason:

- (1) Electrode X is connected to the negative terminal of the battery.
- (2) Electrode X is connected to the positive terminal of the battery.
- (3) X is positively charged, so negative ions move there to accept electrons.
- (4) X is negatively charged, so positive ions move there to release electrons.

21. The direction of the movement of electrons is from electrode Y to electrode X in the electrolyte.

- (A) True
- (B) False

Reason:

- (1) Electrons flow from the negative terminal to the positive terminal of the battery.
- (2) Electrons flow from the positive terminal to the negative terminal of the battery.
- (3) It is the role of ions to carry the electrical charge from electrode Y to electrode X in the electrolyte.
- (4) It is the role of ions to carry the electrical charge from electrode X to electrode Y in the electrolyte.

APPENDIX G2

SECOND VERSION OF THE TWO-TIER MULTIPLE-CHOICE DIAGNOSTIC INSTRUMENT

Instructions

This paper consists of 18 items that evaluate your understanding of electrolysis.

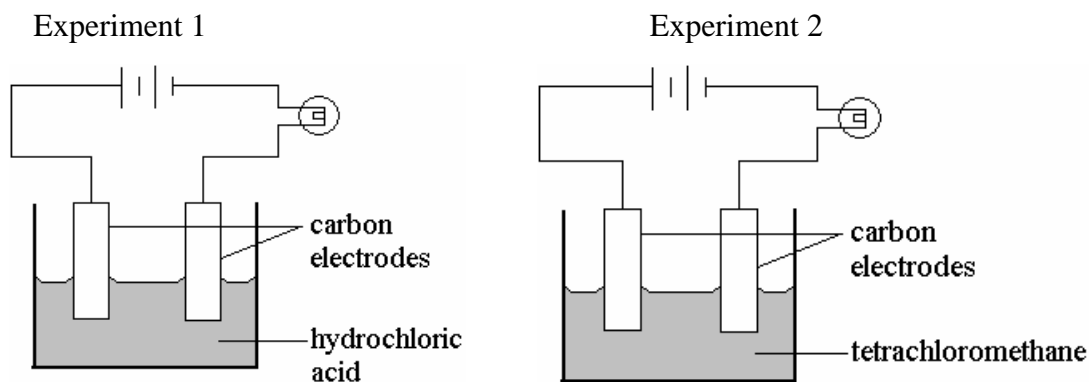
Each question has two parts: a True-False response section followed by a multiple-choice reason.

For each item, you are asked to make one choice from the True-False response section and record your answer in the box provided.

Then choose one of the reasons from the multiple-choice reason section that best matches your answer to the first part of the item and record your answer in the second box.

Item 1

In the two experiments below we would expect the bulb to light up only in Experiment 1.



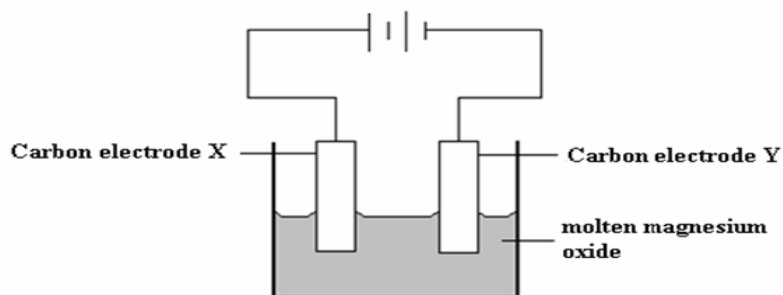
- (A) True
- (B) False

Reason:

- (1) Tetrachloromethane contains more ions.
- (2) Tetrachloromethane consists of free moving ions.
- (3) Hydrochloric acid consists of free moving ions.
- (4) The carbon anode dissolves producing ions.

Item 2

The diagram shows the electrolysis of molten magnesium oxide.



Electrode X is the anode.

- (A) True
- (B) False

Reason:

- (1) Electrode X is connected to the negative terminal of the battery.
- (2) Electrode X is connected to the positive terminal of the battery.
- (3) X is positively charged, so negative ions move there to accept electrons.
- (4) X is negatively charged, so positive ions move there to release electrons.

Item 3

In the electrolysis of molten magnesium oxide using carbon electrodes, magnesium is produced at the anode.

- (A) True
- (B) False

Reason:

- (1) Positively charged magnesium ions are attracted to the anode and accept electrons.
- (2) Positively charged magnesium ions are attracted to the cathode and give up electrons.
- (3) Positively charged magnesium ions are attracted to the cathode and accept electrons.
- (4) Positively charged magnesium ions are attracted to the anode and give up electrons.

Item 4

During electrolysis of molten lead(II) bromide using graphite electrodes, reddish fumes of bromine gas and molten lead are produced.

- (A) True
- (B) False

Reason:

- (1) Bromide ions move to the cathode and are oxidised.
- (2) Bromide ions donate electrons at the anode and form bromine molecules.
- (3) Lead(II) ions are positively charged and so move to the anode.
- (4) Oxygen is attracted to the anode.

Item 5

When aqueous iron(II) sulphate is electrolysed using platinum electrodes, the light green colour of the solution becomes fainter.

- (A) True
- (B) False

Reason:

- (1) Neither iron(II) ions nor sulphate ions are discharged, so the concentration of the solution remains unchanged.
- (2) Hydrogen ions and hydroxide ions are discharged, so the concentration of the solution remains unchanged.
- (3) Hydrogen ions and hydroxide ions are discharged, so the concentration of the solution increases.
- (4) The concentration of iron(II) ions decreases as iron is deposited at the cathode.

Item 6

The products of electrolysis of dilute sulphuric acid using inert electrodes are hydrogen at the cathode and oxygen at the anode.

- (A) True
- (B) False

Reason:

- (1) SO_4^{2-} and H^+ ions are selectively discharged.
- (2) SO_4^{2-} and OH^- ions are selectively discharged.
- (3) The electrolyte consists of hydrogen ions and oxygen ions.
- (4) H^+ and OH^- ions are selectively discharged.
- (5) No reaction occurs because platinum electrodes are inert.

Item 7

When dilute sulphuric acid is electrolysed using inert electrodes, the concentration of the electrolyte increases.

- (A) True
- (B) False

Reason:

- (1) Hydrogen and oxygen are selectively discharged, so the concentration of the acid decreases.
- (2) H^+ and SO_4^{2-} ions from the acid are selectively discharged, so the concentration of the acid decreases.
- (3) H^+ and OH^- ions are discharged at the same time, so the concentration remains the same.
- (4) OH^- and H^+ ions are discharged, effectively removing water molecules from the electrolyte.

Item 8

When aqueous copper(II) sulphate is electrolysed using platinum electrodes, a reddish-brown deposit is produced at the cathode. At the same time, the blue colour of the electrolyte remains unchanged.

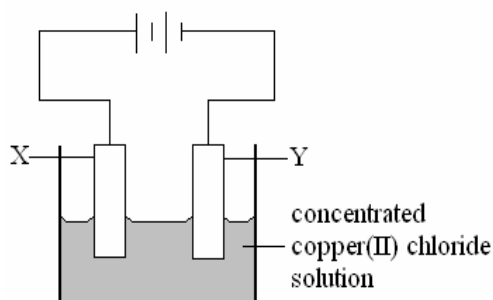
- (A) True
- (B) False

Reason:

- (1) Copper(II) ions are discharged and deposited at the cathode, so the colour of the electrolyte decreases in intensity.
- (2) Copper(II) ions are displaced by platinum atoms, so the colour of the electrolyte decreases in intensity.
- (3) Platinum dissolves in the electrolyte, so the colour of the electrolyte increases in intensity.
- (4) Platinum electrodes are inert, so the colour of the electrolyte remains the same.

Item 9

The diagram below shows an electrolytic cell in which an electric current passes through a concentrated aqueous solution of copper(II) chloride using inert graphite electrodes.



At electrode X, chloride ions are oxidised.

- (A) True
- (B) False

Reason:

- (1) Cu^{2+} ions move to X and accept electrons.
- (2) Cu^{2+} ions move to X and give up electrons.
- (3) Cl^- ions move to X and accept electrons.
- (4) Cl^- ions move to X and give up electrons.

Item 10

When aqueous zinc nitrate is electrolysed using graphite electrodes, bubbles of gas are given off only at the cathode.

- (A) True
- (B) False

Reason:

- (1) H^+ and OH^- are selectively discharged over Zn^{2+} and NO_3^- ions.
- (2) Hydrogen ions are discharged at the cathode, producing hydrogen gas.
- (3) Reaction occurs between zinc ions and the graphite electrodes.
- (4) Zinc is deposited at the cathode.

Item 11

In order to electroplate a metal spoon with silver using aqueous silver nitrate as electrolyte, the spoon should be used as the anode.

- (A) True
- (B) False

Reason:

- (1) Ag^+ ions are attracted to the anode and selectively discharged.
- (2) Ag^+ ions are attracted to the cathode and selectively discharged.
- (3) H^+ ions are attracted to the cathode and selectively discharged.
- (4) H^+ ions are attracted to the anode and selectively discharged.

Item 12

In order to purify an impure copper plate using aqueous copper(II) sulphate, a pure copper plate must be used as the cathode.

- (A) True
- (B) False

Reason:

- (1) Cu^{2+} ions are attracted to the anode and selectively discharged.
- (2) Cu^{2+} ions are attracted to the cathode and selectively discharged.
- (3) H^+ ions present in water are attracted to the cathode and selectively discharged.
- (4) H^+ ions present in water are attracted to the anode and selectively discharged.

Item 13

In the manufacture of chlorine by electrolysis of concentrated aqueous sodium chloride using graphite electrodes, hydrogen gas is also produced.

- (A) True
- (B) False

Reason:

- (1) Hydrogen ions are preferably discharged over hydroxide ions.
- (2) Hydrogen ions are selectively discharged over sodium ions.
- (3) Aqueous sodium chloride does not contain hydrogen ions.
- (4) The concentration of hydrogen ions is very low.

Item 14

In the extraction of aluminium by the electrolysis of molten aluminium oxide using graphite electrodes, the graphite anode has to be periodically replaced.

- (A) True
- (B) False

Reason:

- (1) The anode dissolves in the hot molten aluminium oxide.
- (2) The oxygen produced at high temperatures reacts with the anode.
- (3) The cathode dissolves in the hot molten aluminium oxide.
- (4) The oxygen produced at high temperatures reacts with the cathode.

Item 15

The use of electrolysis in industry causes pollution of the environment.

- (A) True
- (B) False

Reason:

- (1) Gases such as hydrogen and oxygen are released into the atmosphere.
- (2) Chemical wastes are released into the environment after proper treatment.
- (3) Heavy metal ions such as cadmium and nickel ions are released into water sources.

Items 16 -18 are three examples in which electrolysis is used in industry for electroplating.

Item 16

In the motor industry, electroplated nickel and chromium are widely used as the coating system.

- (A) True
- (B) False

Reason:

- (1) The metals are cheap and affordable.
- (2) The metals produce a shiny surface and can prevent rusting.
- (3) The metals do not form a strongly adhering coating.
- (4) The metals have high boiling and melting points.

Item 17

Cutlery items are often electroplated with silver alone, not with silver and nickel.

- (A) True
- (B) False

Reason:

- (1) Silver is too expensive.
- (2) The alloy is less brittle.
- (3) To prevent cutlery from rusting.
- (4) Nickel is poisonous.

Item 18

Gold-plated wrist watches are more expensive than gold watches.

- (A) True
- (B) False

Reason:

- (1) The process of gold-plating is complicated and time-consuming.
- (2) Gold-plated watches are coated with a thin layer of gold.
- (3) Gold-plated watches require more gold than gold watches.
- (4) Gold-plated watches are more attractive than gold watches.

APPENDIX G3

SOLUTIONS TO THE FIRST VERSION OF THE TWO-TIER MULTIPLE CHOICE DIAGNOSTIC INSTRUMENT ON ELECTROLYSIS (APPENDIX G1)

	Item Number	Content Choice	Reason Choice
	1	A	3
	2	A	2
	3	A	2
	4	B	4
	5	B	3
	6	A	4
	7	B	1
	8	A	4
	9	B	1
	10	A	3
	11	B	2
	12	A	2
	13	B	2
	14	B	4
	15	A	2
	16	A	3
	17	A	2
	18	B	1
	19	B	2
	20	A	2
	21	B	1

APPENDIX G4

SOLUTIONS TO THE SECOND VERSION OF THE TWO-TIER MULTIPLE CHOICE DIAGNOSTIC INSTRUMENT ON ELECTROLYSIS (APPENDIX G2)

	Item Number	Content Choice	Reason Choice
	1	A	3
	2	A	2
	3	B	4
	4	A	2
	5	B	3
	6	A	4
	7	A	3
	8	B	1
	9	A	4
	10	B	1
	11	B	2
	12	A	4
	13	A	2
	14	A	2
	15	A	3
	16	A	3
	17	A	4
	18	B	2

APPENDIX H

FINAL VERSION OF ELECTROLYSIS DIAGNOSTIC INSTRUMENT

Instructions to Students

Answer all questions on the separate answer sheet provided

This paper consists of 17 items that evaluate your understanding of electrolysis. Each question has two parts: a True-False response section followed by a multiple-choice reason.

For each item, you are asked to make one choice from the True-False response section and record your answer in the box provided.

Then choose one of the reasons from the multiple-choice reason section that best matches your answer to the first part of the item and record your answer in the second box.

Remember it is important to select a reason

Finally, record how confident you are in arriving at the answer for the item by writing a number in the third box using the scale below:

Not at all	1	2	3	4	5	Totally
confident						confident

Do not forget to record your name and other details on your Answer Sheet

Ding Teng Sia
Science and Mathematics Education Centre
Curtin University of Technology
Perth, WA.

ELECTROLYSIS DIAGNOSTIC INSTRUMENT ANSWER SHEET

Name: _____ Class: _____ Age: _____ years

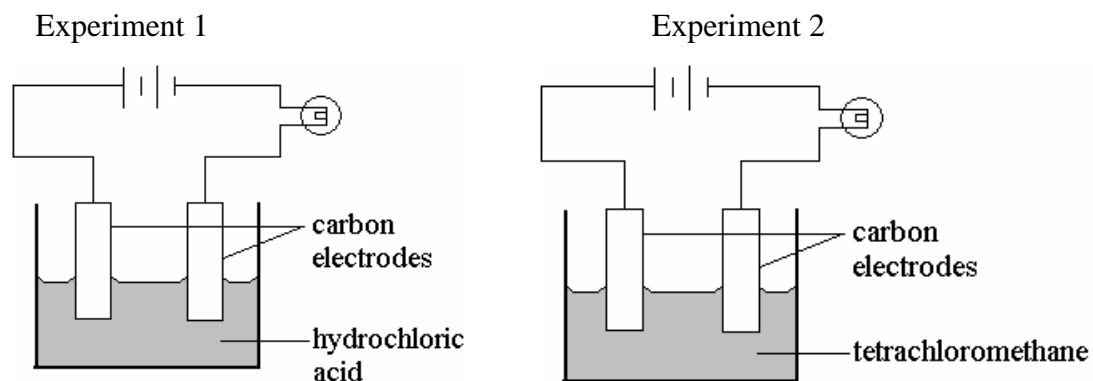
Name of School: _____

Date: _____

	1	Answer		Reason		Confidence	
	2						
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Item 1

In the two experiments below we would expect the bulb to light up only in Experiment 1.



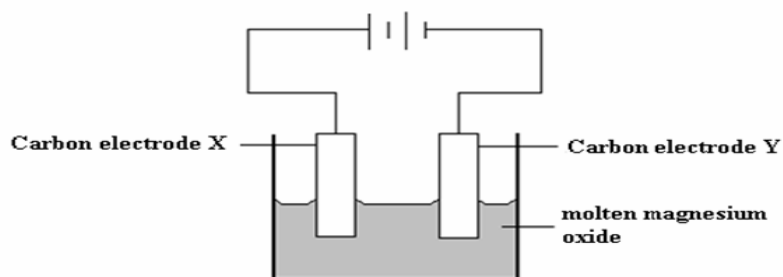
- (A) True
- (B) False

Reason:

- (1) Tetrachloromethane (CCl_4) contains more ions.
- (2) Tetrachloromethane (CCl_4) consists of free moving ions.
- (3) Hydrochloric acid (HCl) consists of free moving ions.
- (4) The carbon anode dissolves producing ions.

Item 2

The diagram shows the electrolysis of molten magnesium oxide.



Electrode X is the anode.

- (A) True
- (B) False

Reason:

- (1) Positive ions move to X and accept electrons.
- (2) Negative ions move to X and donate electrons.
- (3) Positive ions move to Y and donate electrons.
- (4) Negative ions move to Y and accept electrons.

Item 3

In the electrolysis of molten magnesium oxide using carbon electrodes, magnesium is produced at the anode.

- (A) True
- (B) False

Reason:

- (1) Magnesium ions are attracted to the anode and accept electrons.
- (2) Magnesium ions are attracted to the cathode and donate electrons.
- (3) Magnesium ions are attracted to the anode and donate electrons.
- (4) Magnesium ions are attracted to the cathode and accept electrons.

Item 4

During electrolysis of molten lead(II) bromide using graphite electrodes, reddish fumes of bromine gas and molten lead are produced.

- (A) True
- (B) False

Reason:

- (1) Bromide ions move to the cathode and are oxidised.
- (2) Bromide ions donate electrons at the anode and form bromine molecules.
- (3) Lead(II) ions are positively charged and so move to the anode.
- (4) Oxygen is attracted to the anode.

Item 5

When dilute aqueous iron(II) sulphate solution is electrolysed using platinum electrodes, the light green colour of the solution becomes fainter.

- (A) True
- (B) False

Reason:

- (1) Neither iron(II) ions nor sulphate ions are discharged, so the concentration of the solution remains unchanged.
- (2) Hydrogen ions and hydroxide ions are discharged, so the concentration of the solution remains unchanged.
- (3) Hydrogen ions and hydroxide ions are discharged, so the concentration of the solution increases.
- (4) The concentration of iron(II) ions decreases as iron is deposited at the cathode.

Item 6

The products of electrolysis of dilute sulphuric acid using inert electrodes are hydrogen at the cathode and oxygen at the anode.

- (A) True
- (B) False

Reason:

- (1) Sulphate and hydrogen ions are selectively discharged.
- (2) Sulphate and hydroxide ions are selectively discharged.
- (3) The electrolyte consists of hydrogen ions and oxygen ions.
- (4) Hydrogen and hydroxide ions are selectively discharged.
- (5) No reaction occurs because platinum electrodes are inert.

Item 7

When dilute sulphuric acid is electrolysed using inert electrodes, the concentration of the electrolyte increases.

- (A) True
- (B) False

Reason:

- (1) Hydrogen and oxide ions are selectively discharged, so the concentration of the acid decreases.
- (2) Hydrogen and sulphate ions are selectively discharged, so the concentration of the acid decreases.
- (3) Hydrogen and hydroxide ions are selectively discharged, so the concentration of the acid increases.
- (4) Hydrogen and hydroxide ions are selectively discharged, so the concentration of the acid remains the same.

Item 8

When aqueous copper(II) sulphate solution is electrolysed using platinum electrodes, a reddish-brown deposit is produced at the cathode. At the same time, the blue colour of the electrolyte remains unchanged.

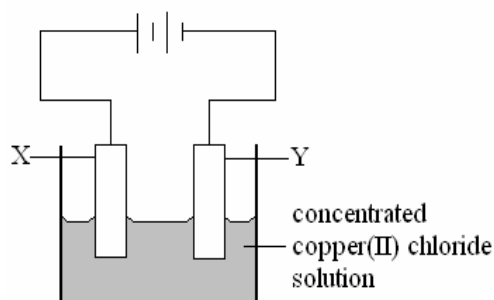
- (A) True
- (B) False

Reason:

- (1) Copper(II) ions are discharged and deposited at the cathode, so the colour of the electrolyte decreases in intensity.
- (2) Copper(II) ions are displaced by platinum atoms, so the colour of the electrolyte decreases in intensity.
- (3) Platinum dissolves in the electrolyte, so the colour of the electrolyte increases in intensity.
- (4) Platinum electrodes are inert, so the colour of the electrolyte remains the same.

Item 9

The diagram below shows an electrolytic cell in which an electric current passes through a concentrated aqueous solution of copper(II) chloride using inert graphite electrodes.



At electrode X, chloride ions are oxidised.

- (A) True
- (B) False

Reason:

- (1) Copper(II) ions move to X and accept electrons.
- (2) Copper(II) ions move to X and donate electrons.
- (3) Chloride ions move to X and accept electrons.
- (4) Chloride ions move to X and donate electrons.

Item 10

When dilute aqueous zinc nitrate solution is electrolysed using graphite electrodes, bubbles of gas are given off only at the cathode.

- (A) True
- (B) False

Reason:

- (1) Hydrogen and hydroxide ions are selectively discharged over zinc and nitrate ions.
- (2) Hydrogen ions are discharged at the cathode, producing hydrogen gas.
- (3) Reaction occurs between zinc ions and the graphite electrodes.
- (4) Zinc is deposited at the cathode.

Item 11

In order to electroplate an iron spoon with silver using aqueous silver nitrate solution as electrolyte, the spoon should be used as the anode.

- (A) True
- (B) False

Reason:

- (1) Silver ions are attracted to the anode and selectively discharged.
- (2) Silver ions are attracted to the cathode and selectively discharged.
- (3) Hydrogen ions are attracted to the cathode and selectively discharged.
- (4) Hydrogen ions are attracted to the anode and selectively discharged.

Item 12

In order to purify an impure copper plate using aqueous copper(II) sulphate solution, a pure copper plate must be used as the cathode.

- (A) True
- (B) False

Reason:

- (1) Hydrogen ions are attracted to the cathode and selectively discharged.
- (2) Hydrogen ions are attracted to the anode and selectively discharged.
- (3) Copper(II) ions are attracted to the anode and selectively discharged.
- (4) Copper(II) ions are attracted to the cathode and selectively discharged.

Item 13

In the manufacture of chlorine by electrolysis of concentrated aqueous sodium chloride solution using graphite electrodes, hydrogen gas is also produced.

- (A) True
- (B) False

Reason:

- (1) Hydrogen ions are preferably discharged over hydroxide ions.
- (2) Hydrogen ions are selectively discharged over sodium ions.
- (3) Aqueous sodium chloride does not contain hydrogen ions.
- (4) The concentration of hydrogen ions is very low.

Item 14

In the extraction of aluminium by the electrolysis of molten aluminium oxide using graphite electrodes, the graphite anode has to be periodically replaced.

- (A) True
- (B) False

Reason:

- (1) The anode dissolves in the hot molten aluminium oxide.
- (2) The oxygen produced at high temperatures reacts with the anode.
- (3) The cathode dissolves in the hot molten aluminium oxide.
- (4) The oxygen produced at high temperatures reacts with the cathode.

Item 15

The use of electrolysis in industry causes pollution of the environment.

- (A) True
- (B) False

Reason:

- (1) Gases such as hydrogen and oxygen are released into the atmosphere.
- (2) Chemical wastes are released into the environment after proper treatment.
- (3) Heavy metal ions such as cadmium and nickel ions are released into water sources.

Items 16 and 17 are two examples in which electrolysis is used in industry for electroplating.

Item 16

In the motor industry, the metals nickel and chromium are used for electroplating.

- (A) True
- (B) False

Reason:

- (1) The metals have high boiling and melting points.
- (2) The metals do not form a strongly adhering coating.
- (3) The metals prevent rusting.
- (4) The metals are chemically unreactive.

Item 17

Cutlery items are often electroplated with silver and nickel.

- (A) True
- (B) False

Reason:

- (1) Nickel reacts readily with silver.
- (2) Silver and nickel are expensive metals.
- (3) The cutlery becomes more brittle.
- (4) The cutlery becomes more resistant to corrosion.

APPENDIX H1

SOLUTIONS TO THE FINAL VERSION OF

ELECTROLYSIS DIAGNOSTIC INSTRUMENT (APPENDIX H)

Item Number	Content Choice	Reason Choice
1	A	3
2	A	2
3	B	4
4	A	2
5	B	3
6	A	4
7	A	3
8	B	1
9	A	4
10	B	1
11	B	2
12	A	4
13	A	2
14	A	2
15	A	3
16	A	3
17	A	4



UNIT PERANCANG EKONOMI
Economic Planning Unit
JABATAN PERDANA MENTERI
Prime Minister's Department
BLOK B5 & B6,
PUSAT PENTADBIRAN KERAJAAN PERSEKUTUAN
62502 PUTRAJAYA
MALAYSIA

APPENDIX J

Telefon: 88883333
Fax: 603-88883798

Ruj. Tuan:
Your Ref.:

Ruj. Kami: UPE: 40/200/19/1532
Our Ref.:

Tarikh:
Date: 13 October 2006

Sia Ding Teng
15 Lorong 2A
Jalan Metro Park
93250 Kuching
Sarawak

APPLICATION TO CONDUCT RESEARCH IN MALAYSIA

With reference to your application dated 25 August 2006, I am pleased to inform you that your application to conduct research in Malaysia has been approved by the **Research Promotion and Co-Ordination Committee, Economic Planning Unit, Prime Minister's Department**. The details of the approval are as follows:

Researcher's name : SIA DING TENG
Passport No. / I. C No: 580228-13-5184
Nationality : MALAYSIA
Title of Research : "DEVELOPMENT AND APPLICATION OF A
DIAGNOSTIC INSTRUMENT TO EVALUATE
SECONDARY STUDENTS' CONCEPTIONS OF
ELECTROLYSIS"

Period of Research Approved: ONE YEAR AND TWO MONTHS

2. Please collect your Research Pass in person from the Economic Planning Unit, Prime Minister's Department, Parcel B, Level 4 Block B5, Federal Government Administrative Centre, 62502 Putrajaya and bring along two (2) passport size photographs. You also required to comply with the rules and regulations stipulated from time to time by the agencies with which you have dealings in the conduct of your research.

3. I would like to draw your attention to the undertaking signed by you that you will submit without cost to the Economic Planning Unit the following documents:

- a) A brief summary of your research findings on completion of your research and before you leave Malaysia; and
- b) Three (3) copies of your final dissertation/publication.


4. Lastly, please submit a copy of your preliminary and final report directly to the State Government where you carried out your research.

ATTENTION

This letter is only to inform you the status of your application and cannot be used as a research pass.

Thank you.

Yours sincerely,


(MUNIRAH ABD. MANAN)
b.p. Ketua Pengarah,
Unit Perancang Ekonomi,
(Seksyen Ekonomi Makro)
Email: munirah@epu.jpm.my
Tel: 88882809/2818/2827

C.c:

Pengarah
Bahagian Perancangan Penyelidikan & Dasar Pendidikan
Kementerian Pelajaran Malaysia
Aras 1-4, Blok E8
Kompleks Kerajaan Parcel E
Pusat Pentadbiran Kerajaan Persekutuan
62604 Putrajaya
(u.p: Dr. Zahri bin Aziz) (Ruj. Tuan: KP(BPPDP)603/011 (5))

Prof. Dr. Nik Meriam Nik Sulaiman
Pengarah,
Institut Pengurusan Penyelidikan dan Perundingan
Universiti Malaya,
C 313, Bangunan IPS,
50603 Kuala Lumpur.



JABATAN PELAJARAN NEGERI SARAWAK
BANGUNAN TUN DATUK PATINGGI
TUANKU HAJI BUJANG
JALAN SIMPANG TIGA
93604 KUCHING
SARAWAK

Telefon: 082-243201
FAX: 082-246750
Kawat: PENDIDIKAN

Ruj Kami : JPS(W)/SPPP/(Lat)153/08/02/05, Jld. 12 (16)

Tarikh : 01 OCT 2007

Cik Sia Ding Teng
Curtin University Of Technology
Science and Mathematics Education Centre
GPO Box U1987
Perth, Western Australia 6845

Tuan/puan

**KEBENARAN UNTUK MENJALANKAN KAJIAN DI SEKOLAH-SEKOLAH, INSTITUT-
INSTITUT PERGURUAN, JABATAN-JABATAN PELAJARAN DAN BAHAGIAN-
BAHAGIAN DI BAWAH KEMENTERIAN PELAJARAN MALAYSIA**

Dengan hormatnya saya merujuk kepada perkara di atas.

2. Sukacita dimaklumkan bahawa pada dasarnya Jabatan Pelajaran Negeri Sarawak tiada sebarang halangan untuk membenarkan tuan menjalankan kajian bertajuk :

**“ Development And Application Of A Diagnostic Instrument To Evaluate
Secondary Students’ Conceptions Of Electrolysis “**

3. Sayugia diingatkan bahawa sepanjang tempoh kajian tersebut, tuan adalah tertakluk kepada peraturan yang sedang berkuatkuasa dan menjalankan kajian seperti tajuk yang diluluskan oleh Bahagian Perancangan dan Penyelidikan Dasar Pendidikan, Kementerian Pelajaran Malaysia bil. KP(BPPDP)603/011(5) bertarikh 21.9.2006.

4. Jabatan ini memohon agar sesalinan laporan kajian dihantar ke Unit Latihan, Jabatan Pelajaran Negeri Sarawak sebaik sahaja selesai untuk tujuan rekod dan rujukan. Dengan surat ini, Pegawai berkenaan adalah dimohon untuk memberi bantuan dan kerjasama yang sewajarnya bagi menjayakan kajian tersebut.

Sekian. Terima kasih.

“BERKHIDMAT UNTUK NEGARA”

Saya yang menurut perintah,


[KUSWADY BIN CHIL]

Sektor Pengurusan Perkhidmatan Pendidikan
b.p Pengarah Pelajaran
Sarawak.

s.k.

Pegawai Pelajaran Gabungan Kuching

Pengetua, SMK Batu Lintang

Pengetua, SMK Green Road, Kuching

Pengetua, SMK St. Thomas, Kuching

Pengetua, SMK St. Joseph, Kuching

Fail (Latihan)